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ELECTRONIC TECHNICIAN TRADE

TRADE TECHNICAL INFORMATION SHEET

BASIC ANTENNA THEORY

INTRODUCTION

A wave length is equal to the velocity of travel of a wave divided by its frequency. Thus,

$$\lambda = \frac{V}{f}$$

where λ = wave length in feet,
V = velocity in feet per second
f = frequency in cycles per second

We can use 984,000,000 feet per second for the quanity V, because the velocity of the electromagnetic wave is the same as that of light. Hence the initial formula becomes:

$$= \frac{984,000,000}{f} \qquad (1)$$

where λ = wave length in feet
f = frequency in cps

If the frequency is given in megacycles instead of cycles, then equation 1 becomes:

$$\lambda = \frac{984}{f} \qquad (2)$$

since there are one million cycles in one megacycle. Half of this figure gives the length of a half-wave:

$$\frac{\lambda}{2} = \frac{492}{f} \qquad (3)$$

This then is the basic formula for the computation of the length of a half-wave length in air or free space. On a wire such as an antenna wire, the velocity is less than 984,000,000 ft/sec. This means that during 360°, or one cycle, the distance covered by the same wave will be less. Consequently, a half wavelength of wire is not correctly given by equation three but by a new equation as follows:

$$\frac{\lambda}{2} = \frac{468}{f} \qquad (4)$$

Since 468 is five percent less than 492 and since this 5% corresponds to the difference in velocity between wave travel in free space and wave travel on the antenna wire; therefore, equation 3 should actually be written as:

$$\frac{\lambda}{2} = \frac{492}{f} \times k \qquad (5)$$

where K = constant that depends upon the medium through which the wave travels.
For free space k = 1. For a thin dipole rod, k = .95 If we used a thick dipole rod, k = .90. Thus half-wave antennas designed for the same frequency may have several different lengths, depending upon the type of material used.

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Kirchhoff's Laws and Simultaneous Equations

Complex D-C circuits or networks require methods for solution which cannot be solved by simple Ohm's law. By applying Kirchhoff's laws and the use of simultaneous equations, which provide a means for solving for two or more unknown, these circuits can be solved for their values.

This information is not intended to replace other sources found in textbooks, but is a consolidation of the fundamental facts. Also it is attempted here to present the facts in another form in hope that a different concept will be of some help.

Kirchhoff's laws stated for solving complex circuits are as follows:

1. The algebraic sum of the EMF's and voltage drops around any closed loop is zero.
2. The algebraic sum of all currents at any junction is zero.

Examples of Law #1:

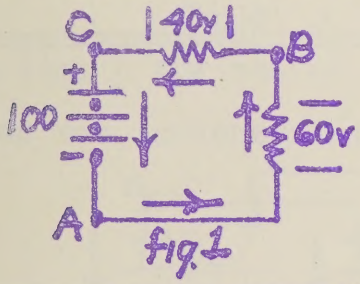


fig.1

Start at point A of fig. 1

A to B = -60

B to C = -40

C to A = +100

Sum 0

-60 -40 +100 = 0

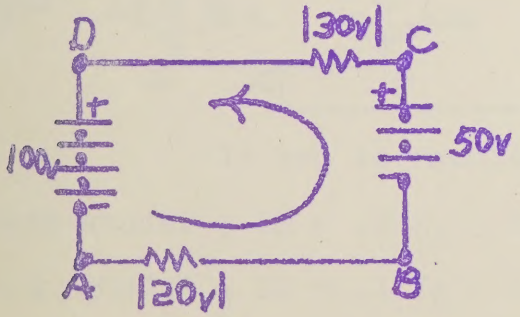


fig.2

Start at point A of Fig. 2

A to B = -20

B to C = -50

C to D = -30

D to A = +100

Sum 0

-20 -50 -30 +100 = 0

By IR drops but disregarding interna l re si stance of EMF's and line l sses:

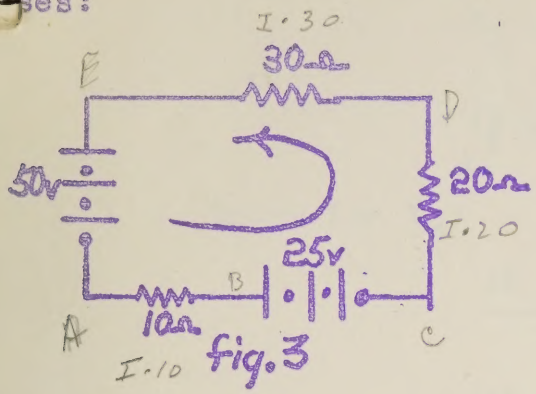


fig. 3

Start at point A of fig. 3

A to B = -I10 I·10

B to C = +25

C to D = -I20 -I10 + 25 -I20 - I30 + 50 ≠ 0

D to E = -I30 -60I + 75 = 0 60I = 75

E to A = +50 I = 1.25 amps

Starting at any point but assuming current flow in the opposite direction would produce a negative current but of the same numerical amount. If the answer is negative simply change to suit the problem. The main rule is to continue in the same direction-----being consistent.

Example of Law #2:

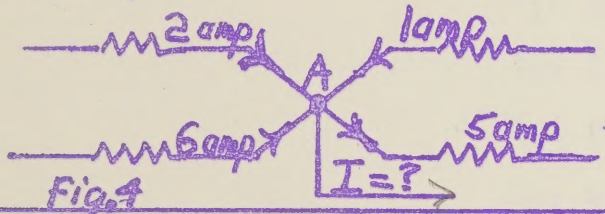


Fig. 4

-I + 2 + 6 + 1 - 5 = 0

-4+2+6+1-5=0 I= 4 amps.

In fig. 5 the use of simultaneous equations makes the solution for the amount of the currents routine once they are mastered.

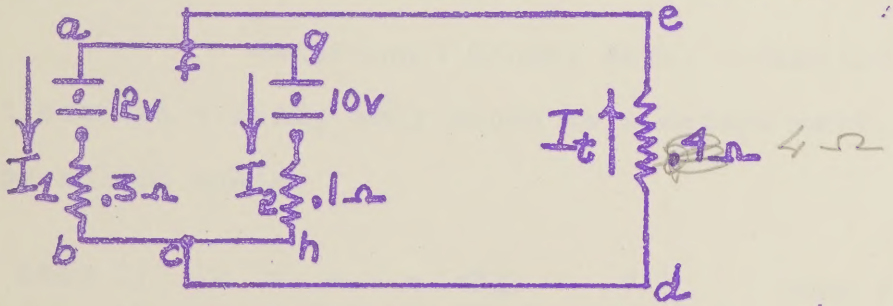


Fig. 5

It can be readily seen that $I_t = I_1 + I_2$

Path abcdef = $12 - .3\,I_1 - 4(I_1 + I_2) = 0$ (1)

Path ghcdef = $10 - .1\,I_2 - 4(I_1 + I_2) = 0$ (2)

(1) can be reduced to:

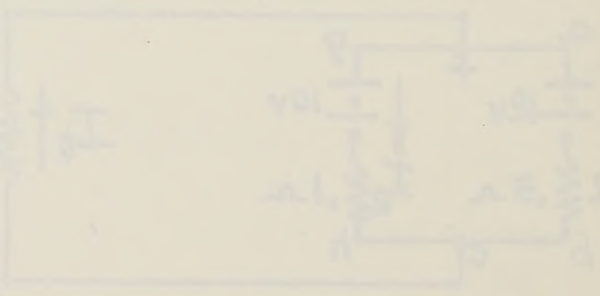
move 12 change signs

Change signs and equation = $.3I_1 + 4(I_1 + I_2) = 12$

$.3I_1 + 4I_1 + 4I_2 = 12$

$4.3I_1 + 4I_2 = 12$ (3)

Repeating for (2) $4I_1 + 4.1I_2 = 10$ (4)



Equations (3) and (4) are simultaneous eqolving two unknowns and can be solved by the comparison method:

$$I_1 = \frac{12 - 4I_2}{4.3} \quad \text{(using (3))}$$

$$I_1 = \frac{10 - 4.1I_2}{4} \quad \text{(using (4))}$$

Solve for I_2:

$$\frac{12 - 4I_2}{4.3} = \frac{10 - 4.1I_2}{4}$$

$$48 - 16\,I_2 = 43 - 17.63I_2$$

$$1.63I_2 = -5$$

$$I_2 = \underline{-3.07 \text{ amps} \quad \text{answer}}$$

Subsituting the value for I_2 in one of the original equations:

$$4.3I_1 + (-12.28) = 12$$

$$4.3I_1 = 24.28$$

$$I_1 = \underline{5.64 \text{ amps.} \quad \text{answer}}$$

$$I_t = I_1 + I_2$$

$$I_t = 5.64 + (-3.07)$$

$$I_t = \underline{2.57 \text{ amps.} \quad \text{answer}}$$

Become familiar with the subtraction, addition, and subsitution for solving simultaneous equations.

Reference: Cookes Math. --Chapter on Simultaneous Equations.

To illustrate a handy tool known as a determinate, equations (3) and (4) will be solved again.

Step 1. $12 \times 4.1 = 492$ (1)

$10 \times 4 = 40$ (2)

Step 2. (1) - (2) = 9.2

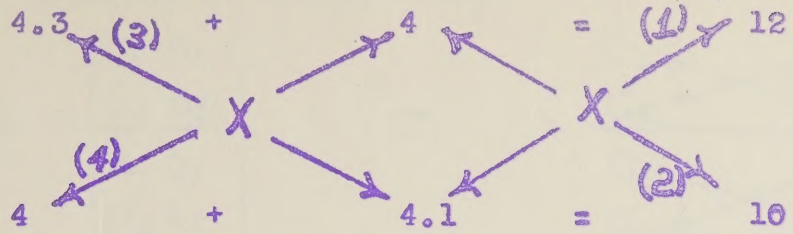
Step 3. $4.3 \times 4.1 = 17.63$ (3)

$4 \times 4 = 16$ (4)

Step 4. (3) - (4) = 1.63

Step 5. $I_1 = \frac{9.2}{1.63} = \underline{5.64 \text{ amp.}}$ answer

Reviewing steps of multiplication of coefficients:



Subtract: (1) - (2)

" : (3) - (4) = I_1

To understand how this equation was formed, set up the two simultaneous equations in a general form: a and b for coefficients, x and y for unknowns, and c for the numerical value of the equation.

$$a_1x + b_1y = C_1 \qquad (1)$$
$$a_2x + b_2y = C_2 \qquad (2)$$

Solving for x and y

Mult. (1) x b_2 $\quad a_1b_2x + b_1b_2y = c_1b_2 \qquad (3)$

Mult. (2) x $-b_1$ $\quad -a_2b_1x - b_1b_2y = -c_1b_1 \qquad (4)$

Add (3) + (4)

$$a_1b_2x \qquad b_1b_2y = c_1b_2$$
$$-a_2b_1x - b_1b_2y = \qquad -c_2b_1$$
$$a_1b_2x - a_2b_1x \quad 0 = c_1b_2 - c_2b_1$$

Simplify $\quad (a_1b_2 - a_2b_1)x = b_2c_1 - b_1c_2$

Solve for x $\quad x = \dfrac{b_2c_1 - b_1c_2}{a_1b_2 - a_2b_1}$

Solve for y (Repeating all steps) $\quad y = \dfrac{a_1c_2 - a_2c_1}{a_1b_2 - a_2b_1}$

General form by notation of determinates:

$$X = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1 \nearrow \searrow b_1 \;\; c_2 \nearrow \searrow b_2}{a_1 \nearrow \searrow b_1 \;\; a_2 \nearrow \searrow b_2}$$

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1 \nearrow \searrow c_1 \;\; a_2 \nearrow \searrow c_2}{a_1 \nearrow \searrow b_1 \;\; a_2 \nearrow \searrow b_2}$$

placing coefficients in equation as an aid:

$$a_1 + b_1 = c_1$$
$$a_2 + b_2 = c_2$$

Review

$$X = \frac{b_2 c_1 - b_1 c_2}{a_1 b_2 - a_2 b_1}$$

$$y = \frac{a_1 c_2 - a_2 c_1}{a_1 b_2 - a_2 b_1}$$

The term $\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}$ is called a determinate and is equal to $c_1 b_2 - b_1 c_2$

If you have mastered equations having two unkowns or using second order determinates, continue your study for 3 unkowns and 3rd order determinates.

References: Electrical Fundamentals (Direct Current)
Army Technical Manual TM11-661
Air Force " Order TO 16-1-218

Mathematics for Electricians and Radiomen--Cooke

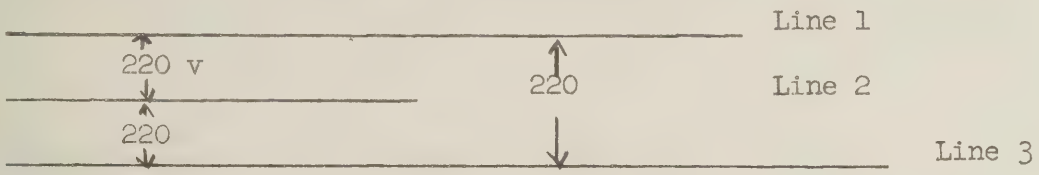
Applied Mathematics for Radio and Communication Engineers
Smith--McGraw Hill

3 PHASE A.C. CIRCUITS

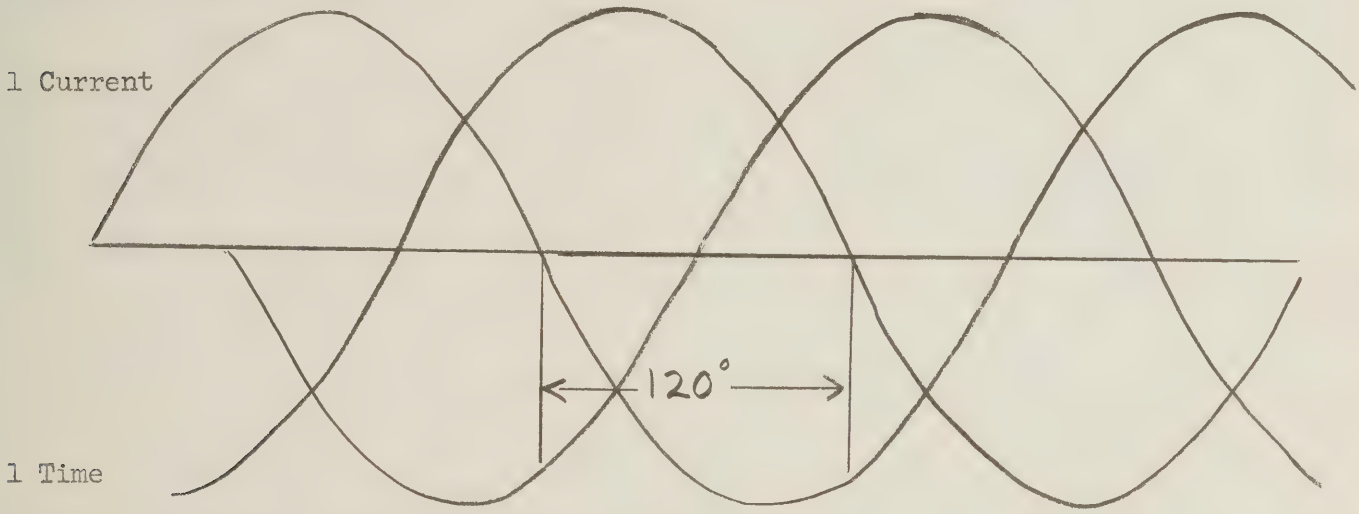
Three phase is so called because three separate currents flow in this method of power distribution and use.

Phase means time-
Thus three phase means: Three currents at a time. The three currents are separated by 120° in true three phase circuits.

Three phase circuits require only three wires.

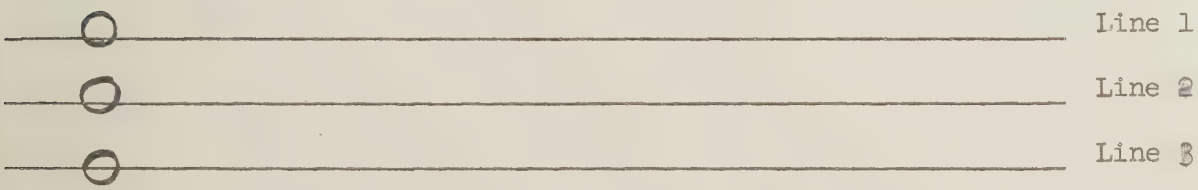


Voltages on a 220v 3 phase system
Three equal voltages



Current in a three phase balanced system.
Note: Currents go through same cycle of events, from zero to max-positive back to zero, then to max-negative, then returns to zero. (one cycle)
Phase 1-2 and 3 are following each other by 1/3 of a cycle or 120°

All currents reach same maximum values in a balanced circuit. Unbalanced circuits have different values of current in each phase or line.

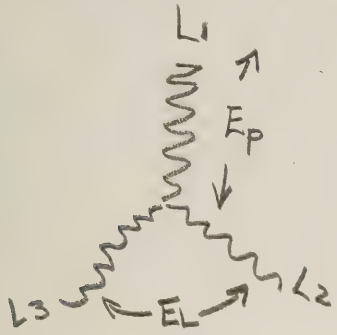


Ammeters measure current in each line.
Balanced - All currents the same.
Unbalanced - Currents differ. Balanced circuits are desired.

Voltage & Current related

Turns = $\frac{\Delta \text{ turns}}{\sqrt{3}}$

Three Phase Connections

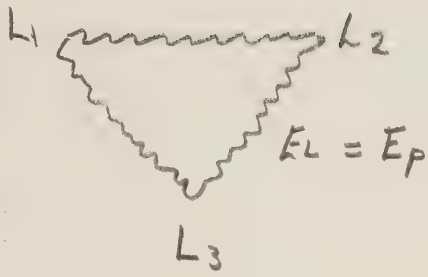


Star

Ep = Phase Voltage

EL = Line Voltage

$Ep = \frac{E_L}{\sqrt{3}}$

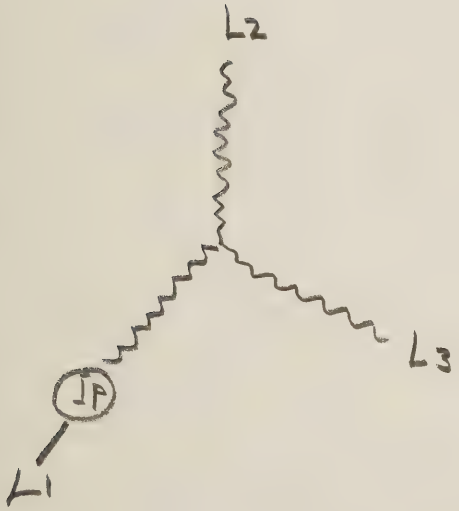


Delta

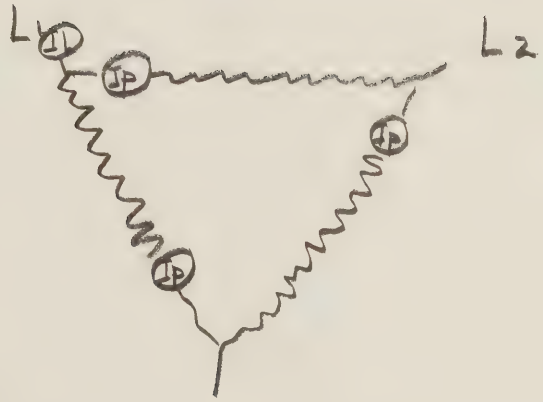
Ep = E

Ip = Phase Current

IL = Line Current



$I_p = I_L$



$I_p = I_L / \sqrt{3}$

$P = E = \sqrt{3}$

$P = \frac{E}{R}(\sqrt{3}) \cdot E \sqrt{3}$

$= \frac{100}{10}\sqrt{3} \times 100 \times \sqrt{3}$

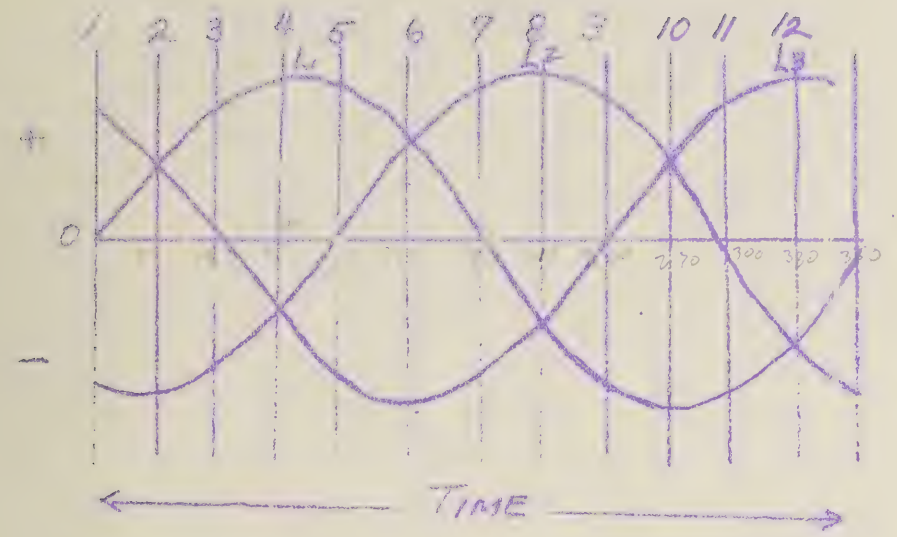
$= 1000 \times 3$

$I = \frac{P}{R}$

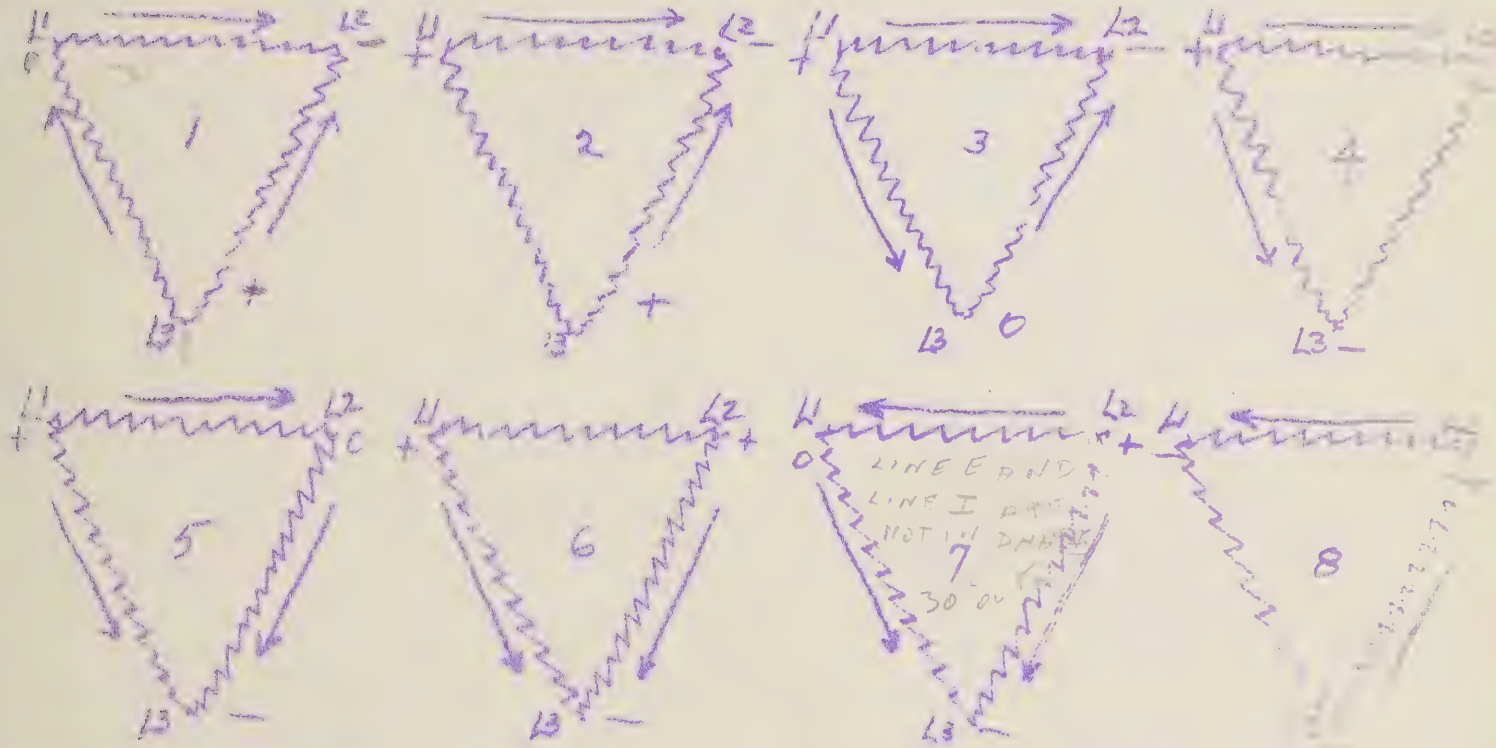
$= \frac{100\sqrt{3}}{10} \quad 100\sqrt{3} =$

$E \times 10 = 1000\,W$

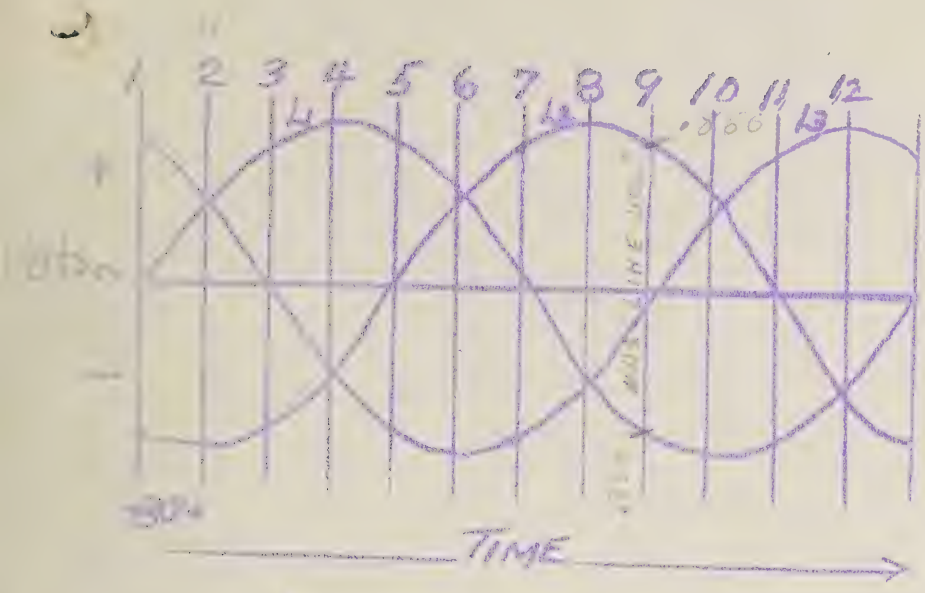
CURRENT FLOW IN 3 PHASE CIRCUIT

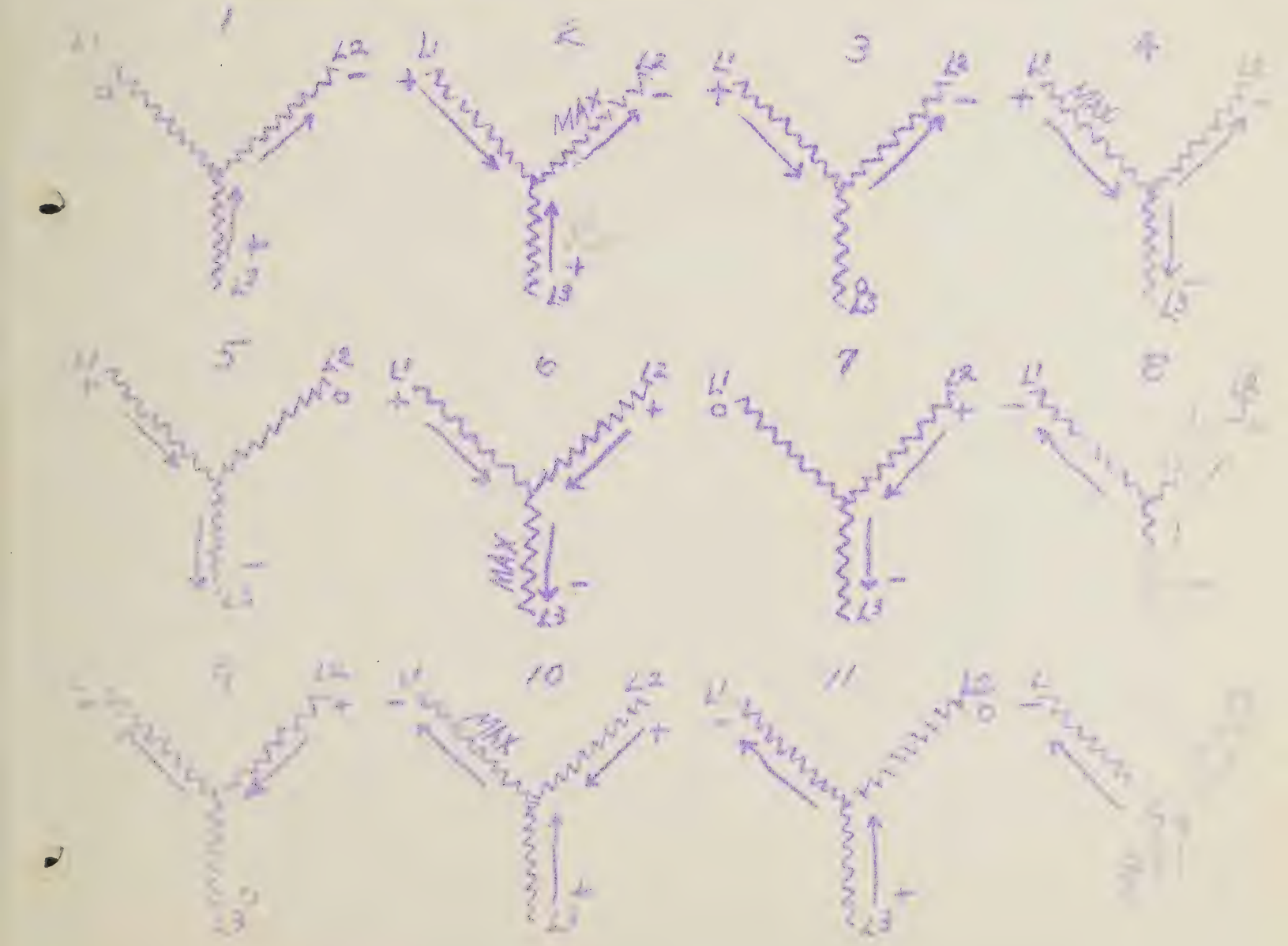


$I_L = I_P \sqrt{3}$



CURRENT FLOW IN STAR CIRCUITS





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AC POWER

INTRODUCTION

In a DC circuit a current of 1 ampere and an applied voltage of 20 volts means that apower of 20 watts has been expended (E x I). A current of 1 ampere with an applied potential of 110 volts in an AC circuit gives absolutely no indication of the power actually consumed - it may be zero, or it may be 110 watts, or it may be any value between 0 and 110. In order to determine the power in an AC circuit, the cosine of the phase angle between the voltage and current must be known. This value is called the power factor. The voltage multiplied by the current (E x I) in an AC circuit is called the apparent power, and the apparent power multiplied by the power factor (E x I x pf) is called the real power or True power.

Apparent power in AC circuit = E x I

True power in AC circuit = E x I x pf

The power factor or phase angle is important in determining the power expended in an AC circuit because a pure inductance or a pure condenser (those which contain no resistance whatsoever) takes no power from a generator even though a current flows when the voltage is applied. Although the energy stored in the magnetic field about a coil produces the same results, the action is illustrated better with a condenser. Assuming that the connecting wires between the generator and the condenser have no resistance, then in a circuit containing only these two components the current flow is calculated by the formula $I = E/X_c$ but the current will do no work. It just flows back and forth between the generator and the condenser without energy being lost in the form of heat or energy being transformed into work such as moving an object. The power factor in this case is zero. (The phase angle is 90° and the cosine of 90° is zero.) Should a resistor be added to the circuit of the generator and the condenser, then the current which is shuttling back and forth in the circuit must flow through the resistor and some energy will be expended in heat. The amount of energy thus lost will depend upon the relative magnitude of the reactance and the resistance which in turn determines the phase angle between the voltage and current. The actual angle need not be calculated in order that the power factor can be found. By definition the cosine of an angle is the adjacent side over the hypotenuse. The adjacent side of any impedance triangle is always the resistance and the hypotenuse is always the impedance, hence, the power formula can be rewritten, True power in an AC circuit = E x I x R/Z.

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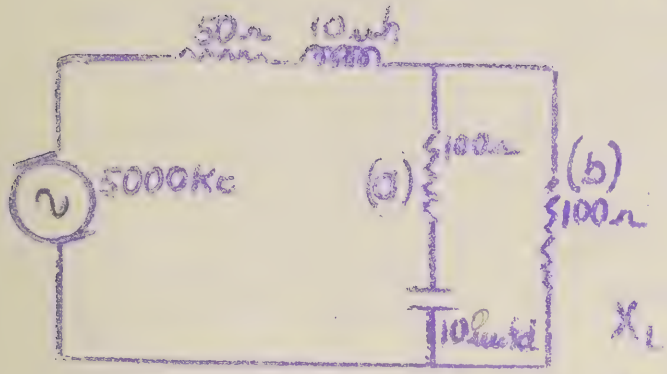
Solving the Complex AC Circuit (Example)



PROBLEM: Solve For The Impedance Across the generator.

Preparation: Find the reactive values of all the capacitors and inductances.

$\omega = 2\pi f = 6.28 \cdot 5 \cdot 10^5 = 3.14 \times 10^6$

$X_L = \omega h = 3.14 \cdot 10^6 \cdot 10 \cdot 10^{-6} = 3.14 \cdot 10^2 = 314\ \Omega$

$X_C = \frac{1}{\omega C} = \frac{1}{3.14 \times 10^6 \cdot 100 \cdot 10^{-6}} = \frac{10^2}{3.14} = 319\ \Omega$

NOTE: Slide Rule Accuracy

Label each branch of the parallel circuit: (a) and (b).

Method I---Solving with Polar and Rectangular Vectors.

Step 1. Find the vector impedance (polar) of each parallel branch.

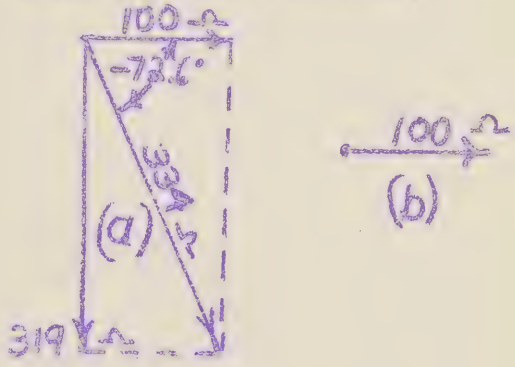
$Z_a = 100 - J\,319\ \Omega$

$\tan\theta = \frac{X_C}{R} = \frac{319}{100} = 3.19$

$\therefore \theta = -72.6°$ also Sine θ .954

$Z_a = \frac{319}{.954} = 334 \angle -72.6°\ \Omega$

$Z_b = 100 + J\,0 = 100 \angle 0°$



Step 2. Assume a voltage across the parallel branch (334 volts).

Step 3. Find the vector current through each branch.

$I_a = \frac{334}{334} = 1 \angle 72.6°$ amps.

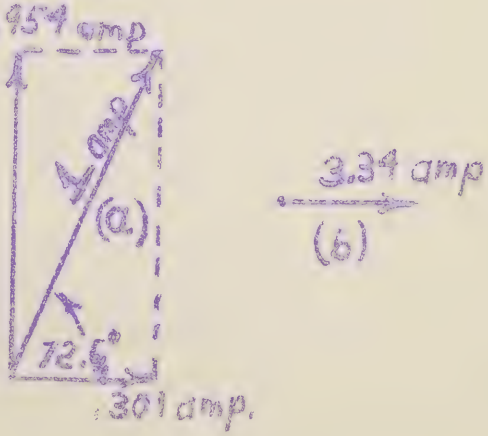
$= 1(\cos 72.6 + J \sin 72.6°)$

$= .301 + J\,.954$ amps

$I_b = \frac{334}{100} = 3.34 \angle 0°$ amps

$= 3.34(\cos 0° + J \sin 0°)$

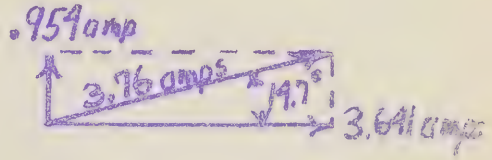
$= 3.34 + J\,0$ amps



Step 4. Compute the total current of the parallel branch by adding the rectangular components and resolve this into its polar form.

$$I_{ab} = (.301 + J.954) + (3.34 + J0)$$

$$= 3.641 + J.954 \text{ amps}$$



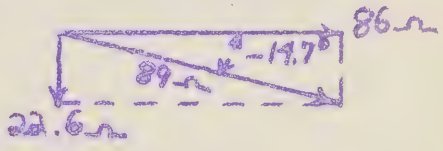
$$\tan\theta = \frac{.954}{3.641} = .262$$

$$\therefore \theta = 14.7^\circ \text{ and } \sin\theta = .254$$

$$I_{ab} = \frac{.954}{.254} = \underline{3.76 \angle 14.7^\circ \text{ amps.}}$$

Step 5. Solve for the impedance of the parallel circuit by dividing the assumed $\hat{E}$ by the vector current.

$$Z_{ab} = \frac{334}{3.76} = \underline{89 \angle -14.7^\circ}$$



Step 6. Change parallel circuit to its equivalent series circuit by solving for the rectangular components.

$$Z_{ab} = 89(\cos 14.7^\circ - J \sin 14.7^\circ)\ \Omega$$

$$= \underline{86 - J22.6\ \Omega}$$

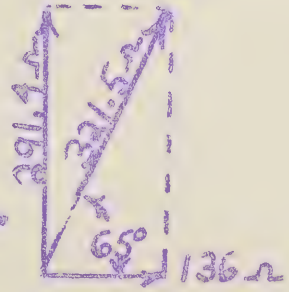
Step 7. Combine this series circuit with the remaining series circuit of the problem and solve for the total impedance.

$$Z_t = (50 + J314) + (86 - J22.6) = 136 + J291.4\ \Omega$$

$$\tan\theta = \frac{291.4}{136} = 2.14$$

$$\therefore \theta = 65^\circ \text{ and } \sin\theta = .907$$

$$Z_t = \frac{291.4}{.907} = \underline{321.5 \angle 65^\circ \text{ ohms.}}$$



Method II---Rationalizing with the Conjugate.
(Review Cooke's Mathematics Essentials--page 161)

Preparation: same as method I. NOTE: Slide Rule Accuracy

Step 1. Solve for vector current through each branch of parallel circuit.

$$I_a = \frac{E}{Z_a} \overset{(assume)}{=} \frac{334}{100 - j319} = \frac{334}{100 - j319} \cdot \frac{100 + j319}{100 + j319} = \frac{33,400 + j106,500}{111,500.}$$

$$= \underline{.3 + j.954 \text{ amps}}$$

$$I_b = \frac{E}{R} = \frac{334}{100} = \underline{3.34 + j0 \text{ amps}}$$

Step 2. Find vectoR current for parallel branch.

$$I_{ab} = (.3 + j.954) + (3.34 + j0) = \underline{3.64 + j.954 \text{ amps}}$$

Step 3. Compute the impedance of the parallel circuit.

$$Z_{ab} = \frac{E}{I_{ab}} = \frac{334}{3.64 + j.954} = \frac{334}{3.64 + j.954} \cdot \frac{3.64 - j.954}{3.64 - j.954}$$

$$= \frac{1215 - j318}{14.12} = \underline{86 - j22.6 \ \Omega}$$

Step 4. Solve for the total impedance of the circuit.

$$Z_t = (50 + j314) + (86 - j22.6) = \underline{136 + j291.4 \ \Omega \text{ answer}}$$

$$\tan\theta = \frac{291.4}{136} = 2.14$$

$$\therefore \theta = 65^\circ \text{ and } \sin\theta = .907$$

$$Z_t = \frac{291.4}{.907} = \underline{321.5 \angle 65^\circ \ \Omega \text{ answer}}$$

INFORMATION SHEET

MICROPHONE CHARACTERISTICS

TYPE	DIRECTIVITY	OUTPUT LEVEL	OUTPUT IMPEDANCE	FREQUENCY RANGE
Velocity	Bidirectional	-55 dbm	50/250 ohms	30-15,000 cps
Dynamic	Nondirectional	-55 dbm	50/250 ohms	40-10,000 cps
Crystal	Nondirectional	-51 dbm	1 meg. approx	40-10,000 cps
Condenser	Nondirectional	-55 to -50 dbm after preamp.	10 meg. approx requires preamp.	30-15,000 cps
Carbon	Nondirectional	-45 dbm	100 ohms	100-4,000 cps

PHONO PICKUP CHARACTERISTICS

TYPE	LOAD IMPEDANCE	OUTPUT LEVEL
Crystal	1 meg. approx.	1 volt approx.
Variable Reluctance G. E. Pickering	6,800 ohms approx. 3,000 ohms approx.	.01 volt .055 volts
Dynamic	50-100 ohms	.01 volts
Strain guage	100-½ meg	.005 volts
Zenith Cobra	Special preamp	1 volt after preamp
F. M.	10 meg. preamp	1 volt after preamp

Los Angeles Trade Tech. Jr. College
Instructor: R.H. Oeffinger

ELECTRONICS TECHNICIAN

INFORMATION SHEET

The Decibel

Part I--Understanding the Decibel

For the study of decibels it is nescessary to have an understanding of exponents and logarithms. Ratios envolving the decibel is simply an applica- of logarithms. If logarithms are not clear, stop now and review this area of mathematics.

In electronics, amplifiers and other devices many times must have a comparison ratiowith respect to power gain to produce a desired effect or result. For example: an amplifier with an output of 16 watts must be increased in power so that the human ear will register an increase in loudness of three times from the speaker. Increasing the power output to 48 watts would not be the correct solution, for the ear does not respond with a linear gain in intensity with respect to a linear change in the power producing the sound.

If the human ear responded in equal sensitivity to all levels of sound what would happen to a person listening to a very low level sound that suddenly increased several hundred times? A severe headache at the least if it did not kill him. From this example we realize that nature has constructed our hearing mechanism to be very sensitive for weak sounds and decrease this sensitivity for the louder levels.

A volume of sound must be increased 25% before the ear can register a difference in levels. This new level must be increased another 25% before another increase will be noticed. To illustrate: suppose we have an amplifier with an output of 10 watts. Gradually increasing the power output a difference in level would not be detected until 12.5 watts, which is a 25% increase or 1.25 times as much power. From this level an increase of 25% or 1.25 times must be made before a change in volume level will be noticed---- appx. 14.6 watts.

Using the ratio of 1.25 to 1 to determine the relative loudness of two sounds by determining the number of times 1.25 would go into the ratio of the power of the sounds would give us how many times one sound is louder than the other. Since this ratio must increase in a logaritmic fashion, it can be seen that a more simple system could be used.

In logarithms when a quanity was increased it was a matter of adding the log. values, instead of multiplying. The increase of powercompared to the sensitivity of the ear, must be increased logarithmatically.

EXAMPLE:

The power outputs of two amplifiers are to be compared to actual hearing results---P_1 and P_2

$$N = \log_{10} \frac{P_1}{P_2}$$

Let P_1=500watts and P_2= 5watts

Then $N = \log_{10} \frac{500}{5} = \log_{10} 100$=10bels answer

Part I--(cont.) Understanding the Decibel.

The unit bel being named for Alexander Graham Bell. The bel is a very large unit and a smaller unit must be used, the decibel. The ratio is in decibel by multiplying by ten:

$$N_{db}=10 \log_{10} \frac{P_1}{P_2} \qquad (1)$$

then 10 bels= 100 decibels

The unit decibel represents the ratio of 1.25 to 1 or every time an increase of 1.25 is recorded a decibel can be added.

The decibel can be used to give the ratio between output and input powers for an amplifier.

EXAMPLE:

An amplifier has an output of 50 watts and an input of 500 milliwatts, what is the db gain?

$$N_{db}=10 \log \frac{50}{.5} = 10 \log 100 = 10 \times 10 = 100\text{db answer}$$

(note: when the base is omitted it is assumed to the base 10)

For a general rule, a power ratio of 2 to 1 represents a 3-db increase.

EXAMPLE:

An increase from 3db to 6db doubles the power. From 6db to 9db doubles the ratio again or 4 times the original power ratio at 3db.

3db = power ratio of 2
6db = power ratio of 4
9db = power ratio of 8

Decibels can be used to express a loss.

EXAMPLE:

What power ratio represents a -30db ?

$$-30db=\log \frac{P_1}{P_2} \times 10$$

Converting to the whole log by dividing by 10

$$3=\log \frac{P_1}{P_2}$$

anti-log of 3= 1000 answer

A power ratio having a logarithm with a characteristic only can be solved easily.

EXAMPLES:

$$10 \log \frac{100}{10} = 10 \log 10 = 10 \times 1 = 10db$$

$$10 \log \frac{1000}{10} = 10 \log 100 = 10 \times 2 = 20db$$

$$10 \log \frac{100,000}{100} = 10 \log 1000 = 10 \times 3 = 30db$$

Part I--(cont.) Understanding the Decibel.

To express the power output of amplifiers, microphones and other devices in decibels, there must be a reference level to express a ratio. An amplifier of 30 db would have no significance unless there is an expression of a ratio comparison. 30 db above 1 milliwatt now gives a definite relationship. Since 30 db equals a power ratio of 1000, then $1000 \times 10^{-3} = 1$ watt, the power output of the amplifier.

The two common reference levels are 1 milliwatt and 6 milliwatts, expressed dbn and db.

In certain cases it is necessary to use current or voltage ratios. The decibel is a power ratio, but by subsituting the formula for power using the resistance as one of the known quanities it is possible to calculate a decibel gain.

FOR CURRENT: $P = I^2R$ $\qquad N_{db} = 10\log \frac{P_1}{P_2} = 10\log \frac{I_1^2R_1}{I_2^2R_2} = 10\log \frac{I_1^2}{I_2^2}$

Input and output resistances being equal they cancel out.

Squaring the log and taking the square root of the ratio:

$$N_{db} = 20\log \frac{I_1}{I_2} \qquad \text{----------(2)}$$

If resistances are unequal:

$$N_{db} = 20\log \frac{I_1\sqrt{R_1}}{I_2\sqrt{R_2}} \qquad \text{----------(3)}$$

FOR VOLTAGE: Repeating the above procedure using $P = \frac{E^2}{R}$

$$N_{db} = 20\log \frac{E_1}{E_2} \qquad \text{----------(3) (4)}$$

If resistance are unequal:

$$N_{db} = 20\log \frac{E_1\sqrt{R_2}}{E_2\sqrt{R_1}} \qquad \text{----------(5)}$$

When voltage or current ratios are used with a common reference level, a common reference resistance must also be stated. Two common reference resistances are 500 and 600 ohms. The VOLUME UNIT (VU) is a unit using one milliwatt with a reference resistance unit of 600 ohms.

Part II--Using the Decibel

EXAMPLE I.

Problem: What is the rating of an amplifier in dbm at 35 watts output?

Solution:

$$N_{dbm}=10\log\frac{35}{10^{-3}}=10\log 35{,}000=10 \times 4.544=45.44\text{dbm answer}$$

EXAMPLE II.

Problem: What is the power output of an amplifier rated at 35 db.

Solution:

$$35db=10\log\frac{P_1}{6 \times 10^{-3}}$$

Dividing by 10

$$3.5=\log\frac{P_1}{6 \times 10^{-3}} \qquad \text{anti-log}3.5=3160=\frac{P_1}{6 \times 10^{-3}} =$$

multiplying by 6×10^{-3}

$$P_1=3160 \times 6 \times 10^{-3} = 18.96 \text{ watts answer}$$

EXAMPLE III.

Problem: A voltage amplifier has a gain of 20. What is its db gain?

Solution: Assume input and output impedances the same (not always true). Then 1 volt input produces 20 volts output.

$$N_{db} = 20\log\frac{20}{1} = 20\log 20 = 20 \times 3.01 = 60db \text{ answer}$$

EXAMPLE IV.

Problem: A microphone is rated at -60db. What is its power output?

Solution: To avoid the use of a negative characteristic, place the larger output in the numerator.

Then: $60db=10\log\frac{6 \times 10^{-3} \text{ (zero reference level)}}{P_{out}}$

anti-log $6=7.78 \times 10^{6} = \frac{6 \times 10^{-3}}{P_{out}}$

Dividing by 10 $\quad 7.78 \times 10^{6} = \frac{6 \times 10^{-3}}{P_{out}}$

multiplying by Pout: $P_{out}=\frac{6 \times 10^{-3}}{7.78 \times 10^{6}} = .773 \times 10^{-9}$ watts or 773×10^{-6} watts. answer

EXAMPLE V.

Problem: Several stages are to be connected in cascade. A pre-amplifier with 10db, an equalizer with -2db, a tone control circuit with -3db, a voltage amplifier with 10db, and a power amplifier with 25db. What is the overall gain?

Solution: Since db is a logarithm, multiplication is accomplished by addition.

10db-2db-3db+10db+25db=40db answer

LOS ANGELES TRADE-TECHNICAL JUNIOR COLLEGE

Conductor Size AWG	Diameter inch	Weight ft. per lb.	Resistance at 20C (68F) ohms per M ft.	Turns per linear in. enamel	Turns per sq. in.	Cross sectional area circular mils	Cross sectional area square mils	Conductor Size AWG
4/0	.4600	1.561	.04901			211,600	166,190	4/0
3/0	.4096	1.963	.06180			167,800	131,790	3/0
2/0	.3648	2.482	.07793			133,100	104,520	2/0
1/0	.3249	3.130	.09827			105,500	82,890	1/0
1	.2893	3.947	.1239			83,690	65,730	1
2	.2576	4.977	.1563			66,370	52,130	2
3	.2294	6.276	.1970			52,640	41,340	3
4	.2043	7.914	.2485			41,740	32,780	4
5	.1819	9.980	.3133			33,100	26,000	5
6	.1620	12.58	.3951			26,250	20,620	6
7	.1443	15.87	.4982			20,820	16,350	7
8	.1285	20.01	.6282	7.6		16,510	12,970	8
9	.1144	25.23	.7921	8.6		13,090	10,280	9
10	.1019	31.82	.9989	9.6	84.8	10,380	8,150	10
11	.09074	40.12	1.260	10.7	105.	8,234	6,470	11
12	.08081	50.59	1,588	12.0	131.	6,530	5,130	12
13	.07196	63.80	2.003	13.5	162.	5,178	4,070	13
14	.06408	80.44	2.525	15	198.	4,107	3,225	14
15	.05707	101.4	3.184	16.8	250.	3,257	2,558	15
16	.05082	127.9	4.016	18.9	306	2,583	2,028	16
17	.04526	161.3	5.064	21.2	372	2,048	1,610	17
18	.04030	203.4	6.385	23.6	454	1,624	1,276	18
19	.03589	256.5	8.051	26.4	553	1,288	1,012	19
20	.03196	323.4	10.15	29.4	723	1,022	802	20
21	.02846	407.8	12.80	33.1	895	810.1	636	21
22	.02535	514.2	16.14	37.0	1070	642.4	505	22
23	.02257	648.4	20.36	41.3	1300	509.5	400	23
24	.02010	817.7	25.67	46.3	1570	404.0	317	24
25	.01790	1,031	32.37	51.7	1910	320.4	252	25
26	.01594	1,300	40.81	58.0	2300	254.1	200	26
27	.01420	1,639	51.47	64.9	2780	201.5	158	27
28	.01264	2,067	64.90	72.7	3350	159.8	126	28
29	.01126	2,607	81.83	81.6	3900	126.7	99.5	29
30	.01003	3,287	103.2	90.5	4660	100.5	78.9	30
31	.008928	4,145	130.1	101	5280	79.70	62.6	31
32	.007950	5,227	164.1	113	6250	63.21	49.6	32
33	.007080	6,591	206.9	127	7360	50.13	39.4	33
34	.006305	8,310	260.9	143	8310	39.75	31.2	34
35	.005615	10,480	329.0	158	8700	31.52	24.8	35
36	.005000	13,210	414.8	175	10700	25.00	19.6	36
37	.004453	16,660	523.1	198		19.83	15.6	37
38	.003965	21,010	659.6	224		15.72	12.3	38
39	.003531	26,500	831.8	248		12.47	9.79	39
40	.003145	33,410	1,049	282		9.888	7.77	40
41	.002800	42,140	1,323			7.842	6.16	41
42	.002494	53,124	1,668			6.219	4.88	42
43	.002221	66,988	2,103			4.932	3.87	43
44	.001978	84,470	2,652			3.911	3.07	44
45	.001761	106,515	3,344			3.102	2.44	45
46	.001568	134,313	4,217			2.460	1.93	46

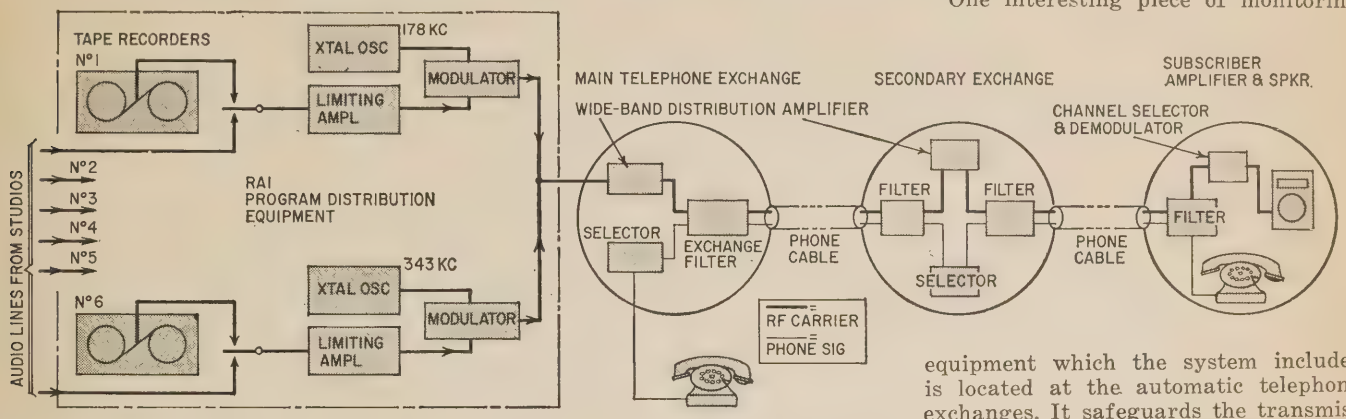
#143-1-500

WIRED BROADCASTS IN ITALY

FOUR principal cities in Italy now have a high-quality wired music service available to home subscribers via carrier-current transmission over telephone lines. The Italian Broadcasting System (RAI) has been providing a choice of up to six programs over this wired-broadcast service since December, 1958, in Rome, Naples and Turin. (Milan was added later.)

The carrier frequencies are from 178 to 343 kc, amplitude-modulated with audio up to 15 kc. There are guard bands 3 kc wide between each of six channels. Five channels provide a choice of varied musical fare, similar in many ways to the First, Second, Third, etc., programs of the BBC in England. The sixth channel is reserved for special events such as international festivals and will ultimately be used for multiplexed stereo.

Programs originate in the RAI Studio Centers, usually from special long-playing tape machines. The audio for each channel is fed into a limiting amplifier. Outputs of each of these limiting amplifiers goes to a modulator. The outputs of the six modulators are then fed into a wide-band mixer–amplifier which amplifies all the modulated rf in its passband, 150 to 400 kc. The mixed carriers travel over leased telephone lines to power amplifiers in automatic telephone exchanges, then out to subscribers over the regular phone lines.



The subscriber's equipment may be merely a filter network to separate the normal telephone signals from the carrier programs, if he has a long-wave receiver which can select frequencies between 178 and 343 kc. But as there are no long-wave broadcast stations in Italy, few Italian receivers cover these frequencies and one additional piece of equipment is usually required. It is a small 6-channel selection and demodulation unit.

One interesting piece of monitoring equipment which the system includes is located at the automatic telephone exchanges. It safeguards the transmissions by indicating loss of any carrier and by continuously measuring the amount of crosstalk. It does this by monitoring 455 kc. Since two of the channels (178 and 275 kc) have a sum frequency of 453 and two others (211 and 244 kc) have a sum frequency of 455 kc, any increase in crosstalk between the stations in either of these pairs will produce a proportional output at 455 kc. The crosstalk threshold is kept below 50 db at all times. END

SERVICING RECORD CHANGERS FASTER *(Continued)*

dropped or worked on by its owner so that a part or parts of the mechanism are damaged.

- Loss of friction between the motor and turntable.

If the changer trips continuously, check:

- Pressure applied to the trip mechanism from the pickup-arm follower.

  Very little pressure is needed to trip the change mechanism. Too much pressure may be the result of incorrect adjustment of the friction between the pickup arm and follower. Excessive friction also can be the result of corrosion, rust and the accumulation of dirt.
- Trip mechanism itself.

  It may be jammed in a position permitting constant tripping.

Record drop

There are several systems for making a record changer drop the next disc. Zenith uses an ejector finger that swings out from a flush position in the spindle and rotates 180° to drop the record. In the VM and many other changers, an ejector lever, normally flush with the spindle, moves forward to drop the record. With many Philco changers, the spindle itself moves forward or "nods" to do the same job. Many models by Motorola had an ejector lever, or tongue, in the record support shelf to push the bottom record from the stack of records. As another example, Webcor used the record support shelf itself, nodding or moving forward, to dislodge the record to be played.

No matter which system is used, there are adjustments for controlling the record dropping action.

- Zenith: The ejector finger must be straight and timed correctly.
- VM: Ejector lever in the spindle, the amount of travel of the lever is variable.
- Philco: The movement of the spindle can be controlled for more or less "nodding."
- Ejector lever within the record support shelf: The movement of the ejector lever can be regulated.
- Webcor: Record support shelf moves forward, amount of record shelf movement can be adjusted.

When it comes to record drop, all record changers have one thing in common—a spindle cap, spindle slider, or the angle at the top of the spindle, which prevents more than one record from dropping at a time.

For record-drop problems, check:

- Thickness of records.

  Records that are too thick will not drop correctly. Also applies to records that are too thin.
- Size of center hole.

  Worn or chipped center hole affects record drop.
- Spindle cap or slider.

  If bent, more than one record will drop. Perhaps several.
- Angle at top of spindle.

  In spindles not using a spindle cap or slider, the angle at the top of the spindle prevents more than one record from dropping at once. If the angle has been changed, several records may drop simultaneously.

(RCA makes a series of records for checking record changers. Among the tests they will aid in making are: landing and tripping, pickup sensitivity, turntable rumble and flutter, and record tracking at various recording levels and stylus pressures. These discs are available from the RCA Victor Custom Record Department, 155 East 24th Street, New York 10, N. Y. Write to the attention of the Sales Service Section. Walsco Electronic Products also makes a series of these discs. For information write to Walter L. Schott Co., 100 West Green St., Rockford, Ill.—*Editor*) END

WHAT is an output WATT?

A new approach to an old problem

By CHARLES B. GRAHAM
ASSOCIATE EDITOR

PEAK power, rated output, and now a new one, *music power* . . . what do they mean? How is the confused audiophile, dealer or technician to know what the power rating of an audio amplifier really signifies?

Many years ago we didn't have this trouble. An amplifier produced, say, "30 watts electrical output." Pure and simple. No complications. Then some fussy character asked, "Yes, 30 watts, but at how much distortion?" and the confusion started.

It was agreed that the *maximum power rating* of an amplifier would be that at which it could continuously reproduce a sine-wave input with no more than 5% distortion. (*Distortion* refers to harmonic distortion throughout this article, as EIA—Electronic Industries Association — and IHFM — The Institute of High Fidelity Manufacturers—standards are based on it . . .)

As audio equipment improved, 5% distortion began to look like too much. Manufacturers started specifying tighter standards, often around 2%. Then with high fidelity, the trend shifted to 1% and even lower distortion at rated output. All this for maximum power with a continuous signal input at 1,000 cycles.

Then one large company came out with a new rating, *peak power*. They pointed out that sudden musical transients, usually the beginnings of notes, are very brief but of high amplitude. Though they require much more power than the body of the music, they last but a fraction of a second, and distortion would, in these brief periods, be virtually inaudible.

Thus, peak-power rating was based on the premise that an amplifier with a given rms rating could amplify transients equal to the peak voltage of the sine wave used for continuous power ratings, or 1.414 times the sine-wave voltage. Since power is equal to the square of the voltage divided by the load resistance (E^2/R) and the peak voltage is 1.414 (the square root of 2) times the sine-wave voltage, the peak power rating of an amplifier was normally set at double its continuous power output. Some amplifiers have appeared with peak ratings up to almost three times the normal undistorted output rating because of conservative continuous power rating published by the manufacturer.

Recently there have been sporadic attempts to set up standards for the high-fidelity industry. Though slowed down by the differences of philosophy between the components makers and the package hi-fi manufacturers (and even within these groups), some progress has been made. The Institute of High Fidelity Manufacturers has issued a booklet, *IHFM Standard Methods of Measurement for Amplifiers*,[1] which will probably be of great use in standardizing methods of measurement, and therefore ratings of amplifiers.

The 8-page booklet sets forth standard laboratory conditions, beginning with power-line specifications (voltage and frequency), temperature, signal input, loads and so on, and rates a power amplifier in terms of continuous power output, *music-power output*, power bandwidth and sensitivity.

Continuous power output is defined as "the greatest single-frequency power that can be obtained for a period of not less than 30 seconds without exceeding rated total harmonic distortion when the amplifier is operated under standard test conditions" (as laid down in the standard).

Music power output is "the greatest single-frequency power that can be obtained under standard test condtions without exceeding rated total harmonic distortion except that the measurement shall be taken immediately after the sudden application of a signal and during a time interval so short that supply voltages within the amplifier have not changed from their no-signal values."

Since it is impractical to measure power output and distortion under such an instantaneous condition, the IHFM specification provides that music power output shall be measured in the same way as indicated for continuous power output "except that the significant supply voltages shall be maintained at the same value as they were under no-signal conditions." The only way this can be done is to substitute temporarily a voltage-regulated power supply for the one built into the amplifier and adjust it for the proper voltage. Then the amplifier signal input is increased (from the previously measured continuous-power-output level) until the measured distortion is the same as the rated maximum for continuous output. This higher output power level is the *music power* output rating, since it is presumed to represent the *instantaneous* power output which the amplifier can handle on transient musical peaks, or the complex waveforms handled in ordinary music.

In comparing the specifications of two amplifiers with equal music power ratings, the one with the better regulated power supply would presumably show a higher continuous power rating than the amplifier with a poorly regulated cheaper power supply. It is also likely that the better regulated job's distortion vs. power output curve would be relatively flat up to the rated continuous power output level, while that of the poorer regulated amplifier would show a rapidly increasing distortion rate toward the rated continuous power level.

Power bandwidth is rated as the range between the lowest and highest frequency at which rated single-tone distortion is equaled, with the measurement made 3 db below rated continuous power output. This is a valuable standard. In the past some makers have stated frequency response in terms of the highest and lowest frequencies at which their amplifiers deliver full power at rated distortion, while others have shown frequency response curves at only 1 or 2 watts power.

The IHFM committee feels that specification of power bandwidth this way is superior to the possible conflict with IM measurements. The latter (SMPTE method) are strictly a measure of low-frequency distortion, but the frequency has never been standardized—it may be 60, 70, 100 cycles or some other choice. Standardizing this frequency might be unfair to some amplifiers. The power bandwidth figure shows clearly at what frequency the power begins to fall off, as compared to the mid-frequency power at rated distortion.

The standard also specifies conditions for measuring voltage output, distortion, hum and noise, damping factor and frequency response, both flat and equalized.

The IHFM has provided a starting point sorely needed in issuing this Standard on Amplifier Measurements (it has issued a similar one on Tuners, also $1). EIA is preparing to adopt a standard similar at least nominally to the IHFM's music power output. END

[1] Institute of High Fidelity Manufacturers, Inc., 125 E. 23rd St., New York 10, N.Y. $1.

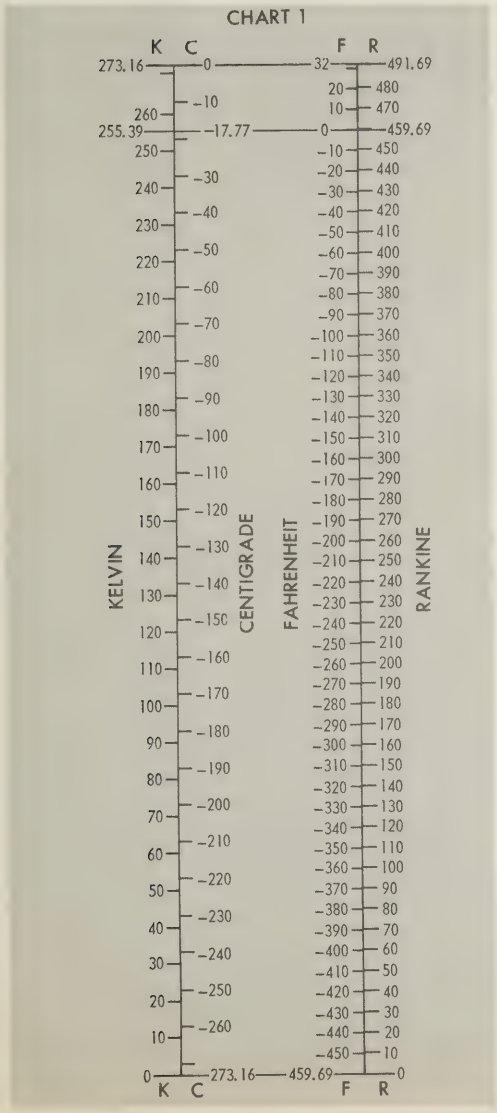
DESIGN DATA REPRINT
DESIGN NEWS

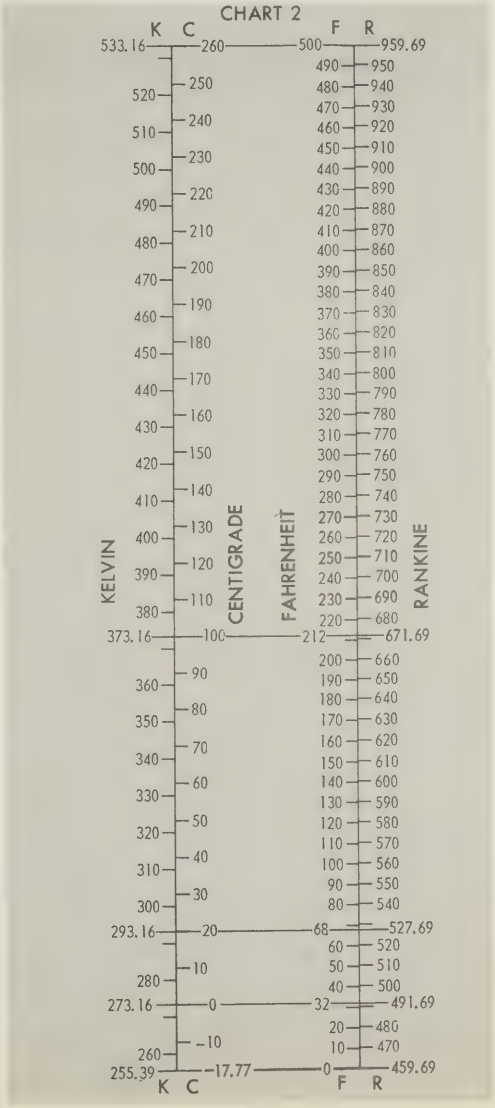
RS No. 526

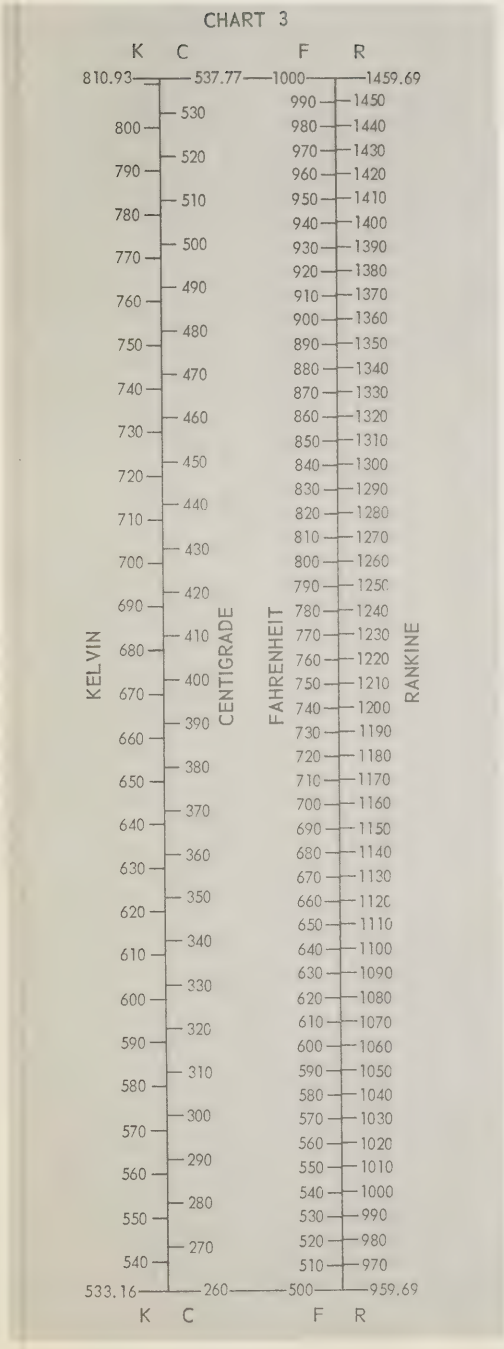
Temperature-Scale Reference Charts

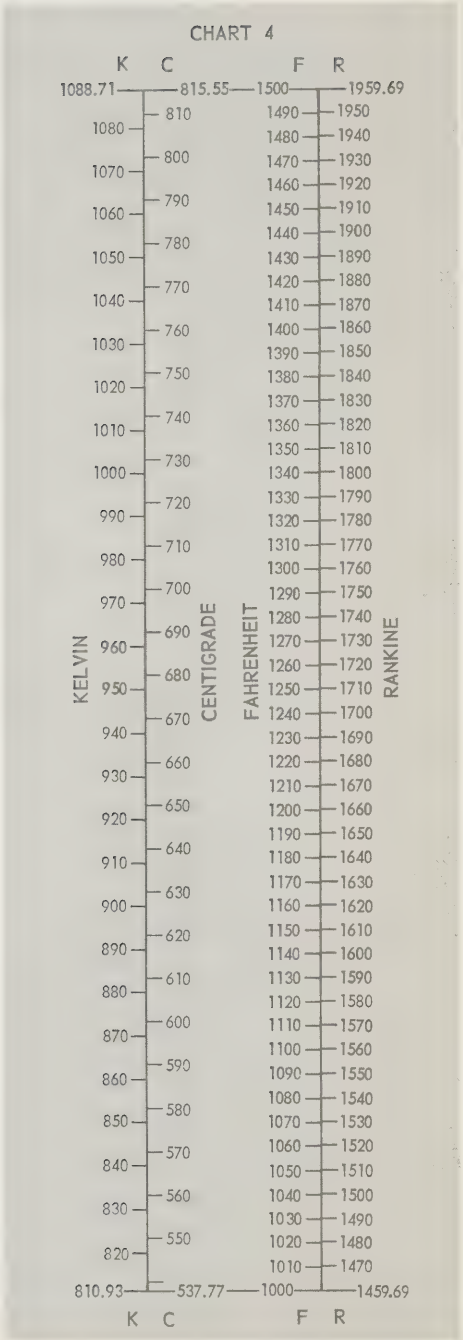
The following charts will be useful in determining approximate temperatures in Fahrenheit and Centigrade (or Celsius) and their respective absolute scales.

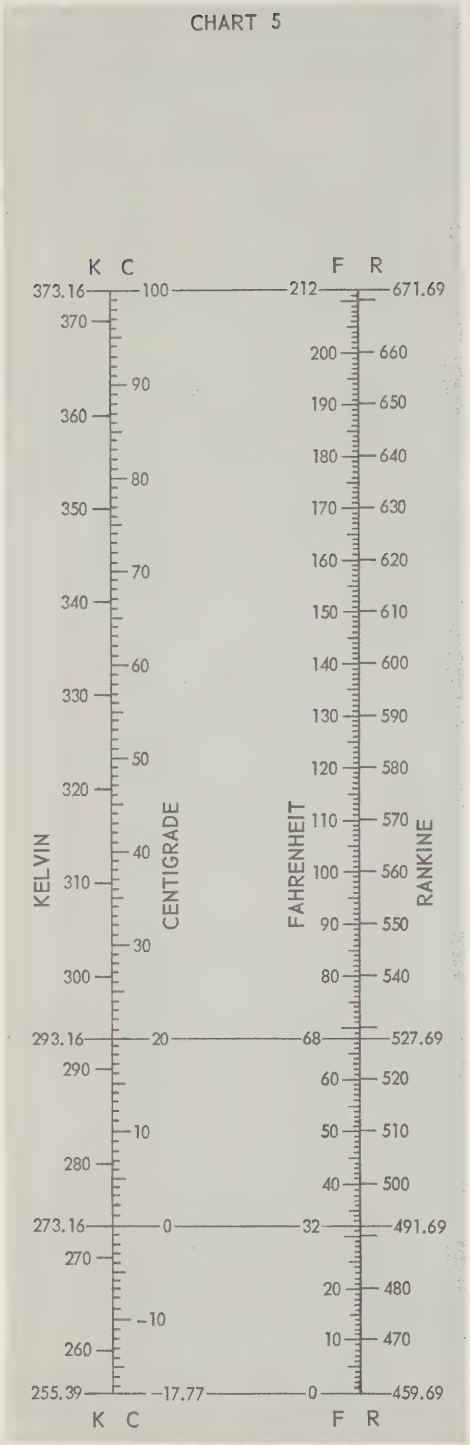
Charts 1 through 4 cover a range from absolute zero to 1500F. Chart 5 expands a portion of Chart 2 and covers from zero to 212F. Chart 6 covers from absolute zero through 4500F.

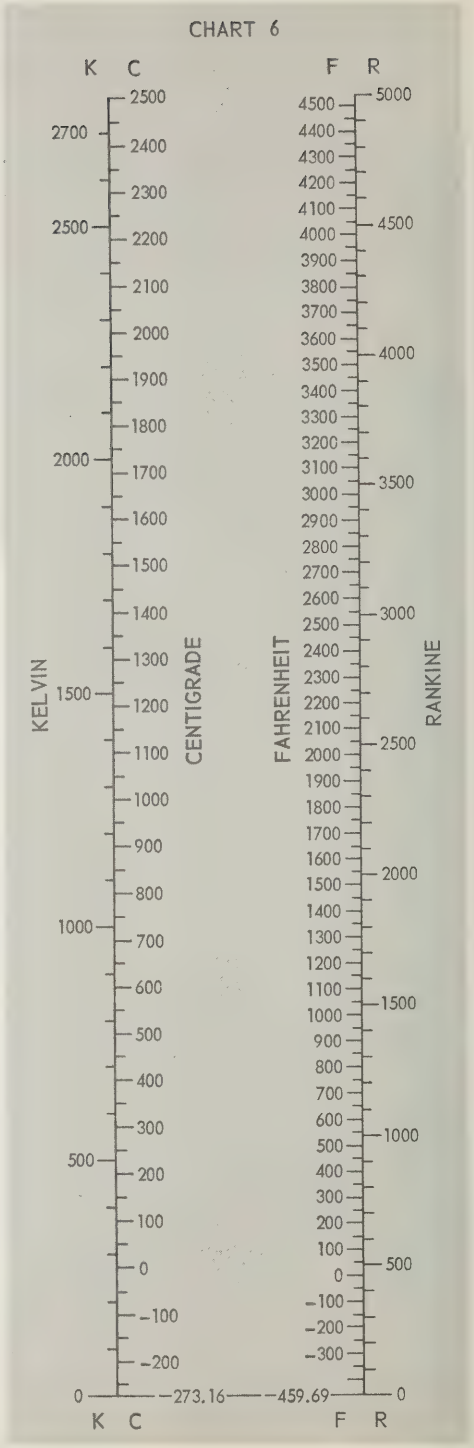












Reprinted from the April 24, 1961 issue of DESIGN NEWS

ALTITUDE CONVERSION CHART

Altitude x 1000 ft.	Temp. Deg. °F	Pressure mm of Hg	Pressure in. of Hg	Pressure psi	Altitude x 1000 ft.	Temp. Deg. °F	Pressure mm of Hg	Pressure in. of Hg	Pressure psi
0	59.00	760.0	29.921	14.70	200.	−2.73	.17	6.718×10^{-3}	3.300×10^{-3}
2.5	50.08	693.8	27.315	13.42	210.	−23.69	1.1×10^{-1}	4.452	2.187
5.	41.17	632.4	24.897	12.23	220.	−44.65	7.3	2.891	1.420
7.5	32.26	575.5	22.656	11.13	230.	−65.60	4.7	1.837	9.023×10^{-4}
10.	23.35	522.7	20.580	10.11	240.	−86.52	2.9	1.139	5.595
12.5	14.45	474.0	18.663	9.167	250.	−105.34	1.7	6.877×10^{-4}	3.378
15.	5.54	429.1	16.893	8.298	260.	−105.34	1.0×10^{-2}	4.104	2.016
17.5	−3.35	387.7	15.262	7.497	270.	−105.34	6.2	2.450	1.203
20.	−12.25	349.5	13.761	6.759	280.	−105.34	3.7	1.463	7.186×10^{-5}
22.5	−21.15	314.5	12.382	6.082	290.	−105.34	2.2	8.746×10^{-5}	4.296
25.	−30.04	282.4	11.118	5.461	300.	−105.3	1.3×10^{-2}	5.229	2.568
27.5	−38.94	253.0	9.960	4.892	325.	−90.12	4.0	1.570	7.712×10^{-6}
30.	−47.83	226.1	8.902	4.373	350.	−62.53	2.5	5.393×10^{-6}	2.649
32.5	−56.72	201.6	7.938	3.899	375.	−30.81	1.5×10^{-4}	2.063	1.013
35.	−65.60	179.3	7.060	3.468	400.	2.76	7.6	8.619×10^{-7}	4.234×10^{-7}
37.5	−69.70	159.1	6.265	3.077	425.	46.73	4.9	3.879	1.905
40.	−69.70	141.2	5.558	2.730	450.	153.6	3.0	1.967	9.662×10^{-8}
42.5	−69.70	125.2	4.931	2.422	475.	259.8	2.0	1.118	5.492
45.	−69.70	111.1	4.375	2.149	500.	365.6	1.3×10^{-3}	6.892×10^{-8}	3.385
47.5	−69.70	98.6	3.882	1.907	550.	575.7	6.7	3.103	1.524
50.	−69.70	87.5	3.444	1.692	600.	755.7	3.7	1.629	8.002×10^{-9}
52.5	−69.70	77.6	3.056	1.501	650.	814.9	2.4	9.266×10^{-9}	4.551
55.	−69.70	68.9	2.711	1.332	700.	875.4	1.4×10^{-4}	5.550	2.726
57.5	−69.70	61.1	2.406	1.182	750.	937.0	9.4	3.471	1.705
60.	−69.70	54.2	2.135	1.049	800.	999.2	6.1	2.251	1.106
70.	−69.70	33.6	1.324	6.503×10^{-1}	850.	1062.	4.2	1.507	7.402×10^{-10}
80.	−69.70	20.9	8.218×10^{-1}	4.037	900.	1125.	2.9	1.037	5.094
90.	−57.20	13.0	5.131	2.520	950.	1188.	2.1	7.304×10^{-10}	3.588
100.	−40.89	8.3	3.264	1.603	1000.	1251.	1.4×10^{-7}	5.256	2.582
110.	−24.59	5.4	2.113	1.038	1100.	1377.	8.0	2.874	1.412
120.	−8.32	3.5	1.390	6.832×10^{-2}	1200.	1503.	5.1	1.670	8.203×10^{-11}
130.	7.94	2.4	9.294×10^{-2}	4.565	1300.	1629.	3.1	1.020	5.010
140.	24.19	1.6	6.299	3.094	1400.	1754.	2.2	6.502×10^{-11}	3.194
150.	40.42	1.1	4.326	2.125	1500.	1878.	1.4	4.293	2.109
160.	49.10	.76	3.004	1.476	1600.	2001.	1.1×10^{-8}	2.921	1.435
170.	49.10	.53	2.090	1.027	1700.	2123.	7.8	2.044	1.004
180.	39.31	.37	1.452	7.132×10^{-3}	1800.	2238.	5.7	1.467×10^{-11}	7.185×10^{-12}
190.	18.28	.25	9.963×10^{-3}	4.894	1900.	——	4.1	——	——
					2000.	——	3.4×10^{-9}	——	——

RELATIVE HUMIDITY CHART

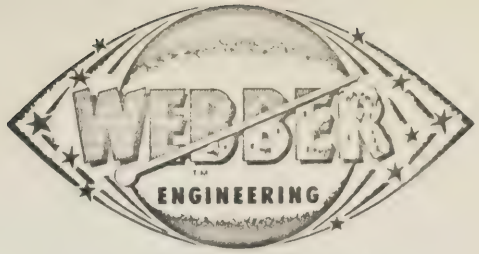
To determine relative humidity from wet and dry bulb temperatures, subtract wet bulb temperature from dry bulb temperature, find number at top representing this difference, then follow down column vertically to intersection of horizontal column, representing dry bulb temperature.

Dry Bulb Deg. F.	DIFFERENCE BETWEEN READINGS OF WET AND DRY BULBS IN DEGREES FAHRENHEIT																												Dry Bulb Deg. F.
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	45	50	55	60	70	
30	89	78	67	56	46	36	26	16	6	0																					30
35	91	81	72	63	54	45	36	27	19	10	0																				35
40	92	83	75	68	60	52	45	37	29	22	7																				40
45	93	86	78	71	64	57	51	44	38	31	18	6																			45
50	93	87	80	74	67	61	55	49	43	38	27	16	5																		50
55	94	88	82	76	70	65	59	54	49	43	33	23	14	5																	55
60	94	89	83	78	73	68	63	58	53	48	39	30	21	13	5	0															60
65	95	90	85	80	75	70	66	61	56	52	44	35	27	20	12	5	0														65
70	95	90	86	81	77	72	68	64	59	55	48	40	33	25	19	12	6	0													70
75	96	91	86	82	78	74	70	66	62	58	51	44	37	30	24	18	12	7	1	0											75
80	96	91	87	83	79	75	72	68	64	61	54	47	41	35	29	23	18	12	7	3	0										80
85	96	92	88	84	80	76	73	70	66	63	56	50	44	38	32	27	22	17	13	8	4	0									85
90	96	92	89	85	81	78	74	71	68	65	58	52	47	41	36	31	26	22	17	13	9	5	1	0							90
95	96	93	89	85	82	79	75	72	69	66	60	54	49	43	38	34	30	25	21	17	13	9	6	2	0						95
100	96	93	89	86	83	80	77	73	70	68	62	56	51	46	41	37	33	28	24	21	17	13	10	7	4						100
104	96	93	90	86	83	80	77	74	71	69	63	58	52	48	43	39	35	31	27	23											104
108	96	93	90	87	84	81	78	75	72	70	64	59	54	49	45	41	37	33	29	26	22	19									108
112	96	93	90	87	84	81	78	75	73	70	65	60	55	51	47	42	38	35	31	28	24	21	18	15							112
116	97	93	90	88	84	82	79	76	74	71	66	61	56	52	48	44	40	36	33	29	26	24	20	17	14						116
120	97	94	91	88	85	82	79	77	74	72	66	62	57	53	49	45	41	38	34	31	28	25	22	19	16	10					120
124	97	94	91	88	85	83	80	77	75	72	67	63	58	54	51	46	43	39	36	33	29	27	24	21	18	13					124
128	97	94	91	89	86	83	80	78	76	73	68	64	59	55	52	47	44	40	37	34	31	28	25	23	20	15					128
132	97	94	92	89	86	83	81	78	76	74	69	65	60	56	53	49	45	42	39	35	32	30	27	24	22	16	11				132
136	97	94	92	89	86	84	81	79	77	74	69	65	61	57	53	50	46	43	40	37	34	31	28	26	24	18	13				136
140	97	94	92	89	87	84	81	79	77	75	70	66	62	58	54	51	47	44	41	38	35	33	30	27	25	19	14	10			140
144	97	95	92	89	87	84	82	80	78	75	71	67	63	59	55	52	48	45	42	39	36	34	31	29	26	21	16	11			144
148	97	95	92	90	87	85	82	80	78	76	71	67	63	60	56	53	49	46	43	40	38	35	32	30	28	22	17	13			148
152	98	95	93	90	88	85	83	81	78	76	72	68	64	60	57	53	50	47	44	41	39	36	33	31	29	23	19	14	10		152
156	98	95	93	90	88	85	83	81	79	77	72	69	65	61	58	54	51	48	45	42	40	37	34	32	30	24	20	15	11		156
160	98	95	93	90	88	86	83	81	79	77	73	69	65	62	58	55	52	49	46	43	41	38	35	33	31	25	21	17	13		160
164	98	95	93	91	88	86	84	82	80	78	73	70	66	62	59	56	52	49	47	44	41	39	36	34	32	26	22	18	14		164
168	98	95	93	91	88	86	84	82	80	78	74	70	67	63	60	56	53	50	47	45	42	40	37	35	33	28	23	19	15		168
172	98	95	93	91	89	86	84	82	81	78	74	71	67	64	60	57	54	51	48	46	43	41	38	36	34	28	24	20	16		172
176	98	96	94	91	89	87	85	83	81	79	75	71	68	64	61	58	55	52	49	46	44	42	39	37	35	29	25	21	17	10	176
180	98	96	94	91	89	87	85	83	81	79	75	72	68	65	62	58	55	52	50	47	45	42	40	38	35	30	26	22	18	11	180
184	98	96	94	92	89	87	85	83	82	79	76	72	69	65	62	59	56	53	50	48	45	43	41	38	36	31	27	22	19	12	184
188	98	96	94	92	90	87	85	84	82	80	76	73	69	66	63	59	57	54	51	49	46	44	41	39	37	32	27	23	20	13	188
200	98	96	94	92	90	88	86	84	82	80	77	74	70	67	64	61	58	55	53	51	48	46	43	41	39	34	30	26	22	16	200
210	98	96	94	93	90	88	87	85	83	81	78	75	71	68	65	62	60	57	54	52	49	47	45	43	41	36	32	28	24	18	210

TEMPERATURE CONVERSION CHART

To convert Fahrenheit temperature to Centigrade temperature: subtract 32—divide by 1.8.

To convert Centigrade temperature to Fahrenheit temperature: multiply by 1.8—add 32.



−459.4 to −70		−69 to 0		+1 to +69		+70 to +139		+140 to +290		+300 to +1000	
C.	F.	C.	F.	C.	F.	C.	F.	C	F.	C.	F.
−273	−459.4	−56.1	−69	−17.2	1	21.1	70	60.0	140	149	300
−268	−450	−55.5	−68	−16.7	2	21.7	71	60.6	141	154	310
−262	−440	−55.0	−67	−16.1	3	22.2	72	61.1	142	160	320
−257	−430	−54.4	−66	−15.6	4	22.8	73	61.7	143	166	330
−251	−420	−53.9	−65	−15.0	5	23.3	74	62.2	144	171	340
−246	−410	−53.3	−64	−14.4	6	23.9	75	62.8	145	177	350
−240	−400	−52.8	−63	−13.9	7	24.4	76	63.3	146	182	360
		−52.2	−62	−13.3	8	25.0	77	63.9	147	188	370
		−51.7	−61	−12.8	9	25.6	78	64.4	148	193	380
		−51.1	−60			26.1	79	65.0	149	199	390
−234	−390	−50.6	−59	−12.2	10	26.7	80	65.6	150	204	400
−229	−380	−50.0	−58	−11.7	11	27.2	81	66.1	151	210	410
−223	−370	−49.5	−57	−11.1	12	27.8	82	66.7	152	216	420
−218	−360	−48.9	−56	−10.6	13	28.3	83	67.2	153	221	430
−212	−350	−48.4	−55	−10.0	14	28.9	84	67.8	154	227	440
−207	−340	−47.8	−54	−9.44	15	29.4	85	68.3	155	232	450
−201	−330	−47.3	−53	−8.89	16	30.0	86	68.9	156	238	460
−196	−320	−46.7	−52	−8.33	17	30.6	87	69.4	157	243	470
−190	−310	−46.2	−51	−7.78	18	31.1	88	70.0	158	249	480
−184	−300	−45.6	−50	−7.22	19	31.7	89	70.6	159	254	490
−179	−290	−45.0	−49	−6.67	20	32.2	90	71.1	160	260	500
−173	−280	−44.4	−48	−6.11	21	32.8	91	71.7	161	266	510
−169	−273	−43.9	−47	−5.56	22	33.3	92	72.2	162	271	520
−168	−270	−43.3	−46	−5.00	23	33.9	93	72.8	163	277	530
−162	−260	−42.8	−45	−4.44	24	34.4	94	73.3	164	282	540
−157	−250	−42.2	−44	−3.89	25	35.0	95	73.9	165	288	550
−151	−240	−41.7	−43	−3.33	26	35.6	96	74.4	166	293	560
−146	−230	−41.1	−42	−2.78	27	36.1	97	75.0	167	299	570
−140	−220	−40.6	−41	−2.22	28	36.7	98	75.6	168	304	580
−134	−210	−40.0	−40	−1.67	29	37.2	99	76.1	169	310	590
−129	−200										
−123	−190	−39.4	−39	−1.11	30	37.8	100	76.7	170	316	600
−118	−180	−38.8	−38	−0.56	31	38.3	101	77.2	171	321	610
−112	−170	−38.3	−37	0	32	38.9	102	77.8	172	327	620
−107	−160	−37.8	−36	0.56	33	39.4	103	78.3	173	332	630
−101	−150	−37.2	−35	1.11	34	40.0	104	78.9	174	338	640
−95.6	−140	−36.6	−34	1.67	35	40.6	105	79.4	175	343	650
−90.0	−130	−36.1	−33	2.22	36	41.1	106	80.0	176	349	660
−84.4	−120	−35.5	−32	2.78	37	41.7	107	80.6	177	354	670
−78.9	−110	−35.0	−31	3.33	38	42.2	108	81.1	178	360	680
−73.3	−100	−34.4	−30	3.89	39	42.8	109	81.7	179	366	690
−72.8	−99	−33.9	−29	4.44	40	43.3	110	82.2	180	371	700
−72.2	−98	−33.3	−28	5.00	41	43.9	111	82.8	181	377	710
−71.7	−97	−32.8	−27	5.56	42	44.4	112	83.3	182	382	720
−71.1	−96	−32.2	−26	6.11	43	45.0	113	83.9	183	388	730
−70.6	−95	−31.7	−25	6.67	44	45.6	114	84.4	184	393	740
−70.0	−94	−31.1	−24	7.22	45	46.1	115	85.0	185	399	750
−69.5	−93	−30.6	−23	7.78	46	46.7	116	85.6	186	404	760
−68.9	−92	−30.0	−22	8.33	47	47.2	117	86.1	187	410	770
−68.4	−91	−29.5	−21	8.89	48	47.8	118	86.7	188	416	780
−67.8	−90	−28.9	−20	9.44	49	48.3	119	87.2	189	421	790
−67.2	−89	−28.3	−19	10.0	50	48.9	120	87.8	190	427	800
−66.6	−88	−27.7	−18	10.6	51	49.4	121	88.3	191	432	810
−66.1	−87	−27.2	−17	11.1	52	50.0	122	88.9	192	438	820
−65.5	−86	−26.6	−16	11.7	53	50.6	123	89.4	193	443	830
−65.0	−85	−26.1	−15	12.2	54	51.1	124	90.0	194	449	840
−64.4	−84	−25.5	−14	12.8	55	51.7	125	90.6	195	454	850
−63.9	−83	−25.0	−13	13.3	56	52.2	126	91.1	196	460	860
−63.3	−82	−24.4	−12	13.9	57	52.8	127	91.7	197	466	870
−62.8	−81	−23.9	−11	14.4	58	53.3	128	92.2	198	471	880
−62.2	−80	−23.3	−10	15.0	59	53.9	129	92.8	199	477	890
−61.7	−79	−22.8	−9	15.6	60	54.4	130	93.3	200	482	900
−61.1	−78	−22.2	−8	16.1	61	55.0	131	98.9	210	488	910
−60.6	−77	−21.7	−7	16.7	62	55.6	132	100	212	493	920
−60.0	−76	−21.1	−6	17.2	63	56.1	133	104	220	499	930
−59.5	−75	−20.6	−5	17.8	64	56.7	134	110	230	504	940
−58.9	−74	−20.0	−4	18.3	65	57.2	135	116	240	510	950
−58.4	−73	−19.5	−3	18.9	66	57.8	136	121	250	516	960
−57.8	−72	−18.9	−2	19.4	67	58.3	137	127	260	521	970
−57.3	−71	−18.4	−1	20.0	68	58.9	138	132	270	527	980
−56.7	−70	−17.8	0	20.6	69	59.4	139	138	280	532	990
								143	290	538	1000

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Binders With Complete File of Technical Sections

THE DECIBEL

By E. H. Boden,
Advanced Application Engineer

INTRODUCTION

The increasing use of the decibel makes it more and more important that radio and television servicemen and radio amateurs become acquainted with this unit of measurement and know how to properly use it. Catalogs and technical literature are making use of the decibel to describe the performance of amplifiers, antennas and filter networks. Radio amateurs have for sometime used decibels in giving signal strength reports.

The use of decibels provides a convenient shorthand notation for power ratios and simplifies overall communication system analysis.

BASIC DEFINITION OF THE DECIBEL

At one time or another we have all probably read or heard it said that the human ear is non-linear in response to changes in power or energy levels. For example, let's assume we have an audio amplifier that is delivering a pure tone and has an actual power output of 10 watts. Now, research has shown that for the ear to sense that the output has been doubled the actual power output of our amplifier must be increased by 10 times, 100 watts. For the ear to sense an increase of four times, the output of the amplifier must be increased by 1000 times, 10,000 watts, etc. Thus it can be seen that the ear becomes less sensitive to changes in power as the delivered power is increased.

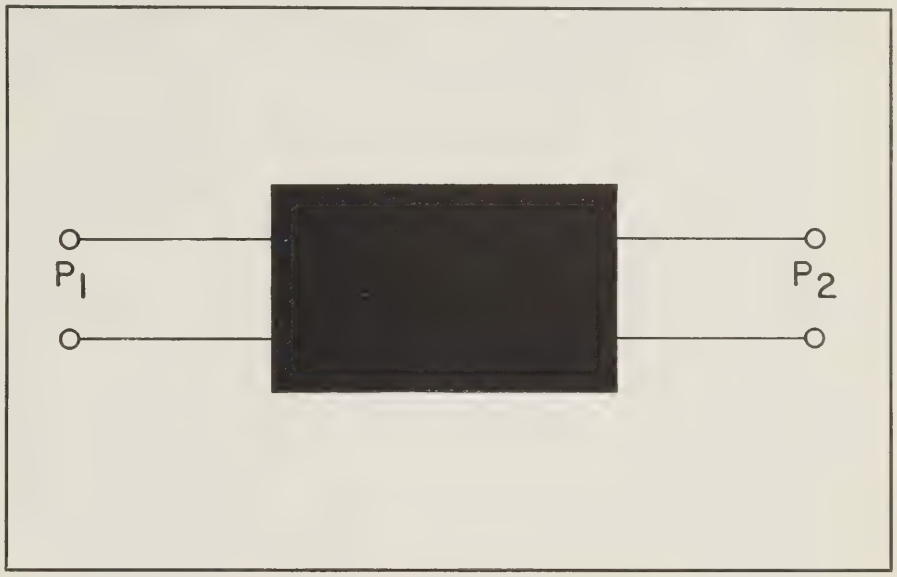

FIG. 1. Amplifier or network having an input of P_1 and output of P_2.

The decibel is simply a relative unit of measurement used to express changes in power based on the ability of the human ear to recognize these changes. As previously stated, application of the decibel as a unit of measurement is not limited to the audio frequency band and/or audio amplifiers. The ease with which the decibel enables us to express power gain and/or power loss, through elimination of the necessity of handling large numbers, has resulted in wide-spread usage.

For those who are mathematically inclined, the decibel is defined by the equation:

$$db = 10 \log_{10} \frac{P_L}{P_S} \qquad (1)$$

where P_L is always the larger power, in watts. P_S is always the smaller power, in watts.

The log function comes from the fact that the response of the ear to changes in power is actually logarithmic. Although equation (1) may be written in a few slightly different forms, the decibel is never anything more or less than equation (1).

USING A DECIBEL TABLE

To find db we can use equation (1) or, for those who prefer to eliminate as much math as possible, we can refer to a Decibel table, Table I. The use of this table is best explained with a few examples. Let's assume we have a gain of 3 decibels. Referring to Table I we find that the corresponding power ratio for a gain of 3 db is 1.99 to 1. In other words, the power output is 1.99 or approximately 2 times the power input. Referring again to Table I, we see that for a power output which is

5 times the power input the gain is 7 db, thus we can work from either direction.

Now, let's see how to handle a power gain of 26 db. First, we look opposite 6 db and find that the corresponding power ratio is 4. In the same manner we find that 20 db represents a power ratio of 100. The power gain, therefore, corresponding to 26 db is 4 x 100 or 400 times.

DB GAIN

To generalize, in Figure 1 we have a "black box." P1 is the power, in watts, that is going in or the input power. P2 is the power, in watts, that we are getting out or the output power. If our box is an amplifier with gain, then P2 will be greater than P1. Let's say by experiment it was found that when a power of 10 milliwatts was put into the amplifier we got 2000 milliwatts (2 watts) out. Let's now find the gain in db. The power gain of the amplifier is found by dividing the power output by the power input:

$$\frac{2000 \text{ mw}}{10 \text{ mw}} = 200$$

Since a power gain of 200 (power ratio of 200 to 1) cannot be read directly in db from Table I it must be broken down into 2 x 100. Referring to Table I we find that a power gain of 2 is 3 db and a power gain of 100 is 20 db. The db gain of the amplifier is simply the sum of 3 db and 20 db or 23 db.

DB LOSS

Many times we find a minus sign in front of a decibel figure. This simply means that there is more power going in than coming out. Now let's say that our "black box," Figure 1, is a network in which there is a loss, i.e., P2 is less than P1. Let's say then, that P1 = 10 mw and P2 = 2 mw. Referring to Table I we find that for a power ratio $\left(\frac{P_L}{P_S}\right)$ of 10/2 = 5. A figure of 7 db is obtained. Since the power input is greater than the power output we say the circuit has a loss of 7 db or a −7 db gain.

RELATIONSHIP TO NOISE FIGURE

Some months back[1] we talked about noise figures of amplifiers. At that time we expressed noise figures in decibels. Here again we were talking about a power ratio. The ratio then was the noise power of the circuit in question as compared to the noise power of an ideal circuit. Ten times the logarithm of this ratio gave us the noise figure in decibels.

TRANSMISSION LINES AND BOOSTERS

Since the advent of directional television antennas we have become accustomed to seeing antennas listed with 5, 6 or 9 db gain. This seems to imply that we are getting some free power in the antenna someplace. What is really happening is we are making an antenna more sensitive in one direction at the expense of sensitivity in other directions. In most cases the gain is relative to a half wave dipole while at times it is relative to a point source (antenna with equal response in all directions). A half wave dipole has a gain of 2 db over that of a point source.

A transmission line may be reduced to a simple network. For a given length, frequency and type of line,[2] there will be a power loss. By taking ten times the logarithm of the sending end power to the receiving end power we will have the db loss of the transmission line, or using Table I.

Before going on, let us see how we can use what we have learned so far. Let us suppose that we have an antenna, amplifiers and lengths of transmission line in order to bring the signal from a remotely located antenna to the receiver. Let us also assume that a satisfactory signal can be obtained at the antenna with a simple folded dipole. When using ordinary flat twin lead there is a

TABLE I

TABLE OF DECIBELS FOR POWER AND VOLTAGE RATIOS

DB	POWER RATIO	VOLTAGE* RATIO	DB	POWER RATIO	VOLTAGE* RATIO
1.0	1.26	1.12	6.0	3.98	1.99
1.2	1.32	1.15	6.2	4.17	2.04
1.4	1.38	1.17	6.4	4.36	2.09
1.6	1.44	1.20	6.6	4.57	2.14
1.8	1.51	1.23	6.8	4.79	2.19
2.0	1.58	1.26	7.0	5.01	2.24
2.2	1.66	1.29	7.2	5.25	2.29
2.4	1.74	1.32	7.4	5.50	2.34
2.6	1.82	1.35	7.6	5.75	2.40
2.8	1.91	1.38	7.8	6.03	2.46
3.0	1.99	1.41	8.0	6.31	2.51
3.2	2.09	1.44	8.2	6.61	2.57
3.4	2.19	1.48	8.4	6.92	2.63
3.6	2.29	1.51	8.6	7.24	2.69
3.8	2.40	1.55	8.8	7.59	2.75
4.0	2.51	1.58	9.0	7.94	2.81
4.2	2.63	1.62	9.2	8.32	2.88
4.4	2.75	1.66	9.4	8.71	2.95
4.6	2.88	1.70	9.6	9.12	3.02
4.8	3.02	1.74	9.8	9.55	3.09
5.0	3.16	1.78	10.0	10.00	3.16
5.2	3.31	1.82	20.0	100.00	10.00
5.4	3.47	1.86	30.0	1,000.00	31.60
5.6	3.63	1.91	40.0	10,000.00	100.00
5.8	3.80	1.95	50.0	100,000.00	316.00

*May be used only when input and output impedances are equal.

transmission line loss of 40 db for the particular length involved. To make up for this 40 db loss, two 20 db boosters may be used. If an antenna of 10 db gain and possibly a tubular twin lead with 10 db less loss is employed only one 20 db booster would be needed. What we are saying is that the db gains must add up to equal the db losses. In this way we can be certain of a good picture.

VOLTAGE AND CURRENT RELATIONSHIPS

It was said earlier that equation (1) could be rewritten in a few slightly different forms. These new forms are derived by substituting the latter two fundamental power relationships in equation (1):

$$P = IE = \frac{E^2}{R} = I^2R \qquad (2)$$

Skipping the mathematics involved our new equations are:

$$db = 20 \log \frac{E_L}{E_S} \qquad (3)$$

and

$$db = 20 \log \frac{I_L}{I_S} \qquad (4)$$

These two relationships, however, hold true only if the input and output resistances of the circuit with which we are working are equal.

Although the application of equation (3) is limited by the fact that input and output resistances must be equal it is still very handy. For example, if we have a booster with a 300 ohm input and output, the gain of the amplifier in db is simply 20 times the log of the input to output voltage ratio. Table I also includes voltage ratios for various db levels, thus eliminating the necessity of handling logarithms.

RESPONSE CURVES

Figure 2 shows the gain characteristics of a typical IF amplifier of a color receiver.[3] Note that the picture brightness carrier is —6 db. This means that the picture carrier power is one-fourth the maximum response of the amplifier. The chroma carrier is at zero db, that is, it is amplified fully, while the sound carrier is down 52 db (1/160,000 the power or 1/400 the voltage level.)

The above methods of describing the IF response curve is also used to describe the characteristics of a video amplifier, a hi-fi amplifier or even a vacuum tube voltmeter.

AMATEUR RADIO

At this point it is interesting to go back and think about some of the signal reports given out in amateur radio. "Your signal here Joe, is 10 db over S-9." This tells Joe that he may decrease his power a factor of 10. Since Joe is running 1 kw to the final, the signal report tells him that he may reduce his power to 100 watts and still have an S-9 signal with a much reduced electric bill.

DBM

Occasionally one finds the use of dbm. This means decibel relative to one milliwatt power. Plus 30 dbm would then equal one watt of power while —3 dbm equals 0.5 milliwatt.

Microphone db ratings have not been standardized. For some, the zero db reference level is one volt at a sound pressure of one dyne per square centimeter while others use one milliwatt at 0.0002 dyne per square centimeter (threshold of hearing).

CONCLUSION

With practice and frequent use one will find the decibel a very convenient tool, i.e., it saves the handling of large numbers (50 db is 100,000 times), and many times, lengthy descriptions. Where a number of amplifiers and transmission lines are involved the overall performance is obtained by a simple algebraic addition.

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[1]Boden, E. H., Noise in Television Receivers, SYLVANIA NEWS, February 1956. Vol. 23, No. 2.

[2]Allen, J S.: An Antenna for UHF TV Reception, SYLVANIA NEWS, March 1952, Vol. 19, No. 3.

[3]Hazeltine Staff—Principles of Color Television, John Wiley & Sons, Inc., New York, 1956, p. 346.

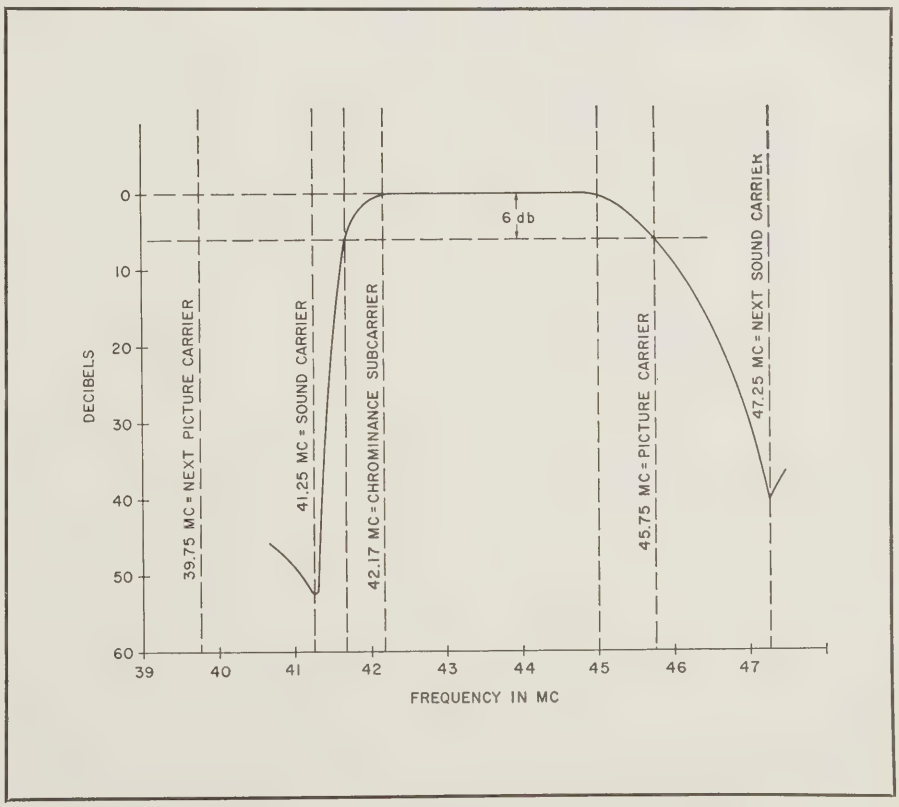

FIG. 2. Gain characteristic of color receiver IF Amplifier.

LOGARITHMS

Editor's Note:

For those who wish to go further into the basic equation for decibels, Mr. Boden has prepared the following review of logarithms.

Some people think that logarithm is a word, like calculus, used by teachers to scare little mathematicians. Fortunately, this is not so. Truly, logarithms are as simple as they are powerful. They were invented by a famous Scottish astronomer, Lord John Napier in 1614 and have been considered[1] the greatest contribution to mathematics and mathematical sciences since the invention of the very numbers we use.

To explain logs, let us first observe that if we write 10^2 we mean 100 and that 10^3 is 1000 and so on. Also $10^1 = 10$. Now let us look at $10^2 \times 10^2$. By expanding the two squares and then performing the multiplication we have $10^2 \times 10^2 = 100 \times 100 = 10{,}000$. But, 10,000 is also 10^4. Now notice what John Napier notices, that by adding the exponents of the first two 10's we get the exponent of another 10 which is the answer. For example, $2 + 2 = 4$ or $10^2 \times 10^2 = 10^4$. In the same way

$$10^1 \times 10^2 = 10^3$$
$$10^1 \times 10^3 = 10^4 \qquad (1)$$
$$10^2 \times 10^3 = 10^5$$

The point is that we performed multiplication by doing addition. If we knew to what power to which we may raise 10 to get other numbers such as 2 and 4 then we could do any kind of multiplication we wanted by simple addition. Table II is a table of just such numbers. Table II is a table of powers to which 10 may be raised in order to give a certain number.

For example, the log 2 = .3010. This then says that if ten is raised to the .3010 power it would equal 2. Now let us use logarithms to solve 2 x 4.

Referring to Table II and looking opposite 2 we see that its log is .3010. In the same way the log of 4 is found to be .6021. Since these two numbers are exponents we add them

$$\begin{aligned} \text{Log } 2 &= .3010 \\ \text{Log } 4 &= .6021 \qquad (2) \\ &\overline{.9031} \end{aligned}$$

The sum is the logarithm of the number which is our answer or 8. Saying it another way, the antilog of .9031 = 8.

Let us now look at another example. Our problem now is 12 x 150. This time we have numbers for which we apparently do not have a logarithm. But, if you notice, we can rewrite both of these numbers

$$12 = 10^1 \times 1.2$$
$$150 = 10^2 \times 1.5$$

Also the log of 10 = 1 and the log $10^2 = 2$ so that from Table II

$$\begin{aligned} \log 12 &= \log 10 + \\ \log 1.2 &= 1 + .0792 = 1.0792 \\ \log 150 &= \log 10^2 + \\ \log 1.5 &= 2 + .1761 = 2.1761 \\ & \overline{3.2553} \end{aligned}$$

Also from Table II we see that the log of 1.8 is .2553 and because our answer has a three in front of the decimal point we multiply 1.8 by 10^3 to obtain the answer of 1800.

Should it be desired to multiply several numbers together, one finds the log of each number, adds the logs of the numbers and then looks up the antilog of the total for the answer.

By the use of logs, division is also simplified. Briefly, to divide 12 by 2 one subtracts the log of 2 from the log of 12.

$$\begin{aligned} \log 12 &= 1.0792 \\ \log 2 &= -.3010 \\ & \overline{.7782} \end{aligned}$$

Antilog .7782 = 6.0

Another interesting feature of logarithms is the ease with which one may raise a number to any power or take any root of a number. For example, to find the square of 3 we find the log of 3, multiply it by 2 and get the antilog.

$$2 \log 3.0 = 2 \times .4771 = .9542$$

The antilog of .9542 = 9.0

In the above we have used 10 as our number to be raised by certain powers. When we do this our system is termed "to the base 10" and is written $\log_{10}$. When used with decibels the base is always 10. When it is understood to be to the base 10 the 10 may be omitted.

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[1]Kasner and Newman, Mathematics and the Imagination, p. 81, Simon and Schuster 1940.

TABLE II

A SHORT TABLE OF LOGARITHMS

N	1	N	1	N	1
1.0	.0000	4.1	.6128	7.2	.8573
1.1	.0414	4.2	.6232	7.3	.8633
1.2	.0792	4.3	.6335	7.4	.8692
1.3	.1139	4.4	.6435	7.5	.8751
1.4	.1461	4.5	.6532	7.6	.8808
1.5	.1761	4.6	.6628	7.7	.8865
1.6	.2041	4.7	.6721	7.8	.8921
1.7	.2304	4.8	.6812	7.9	.8976
1.8	.2553	4.9	.6902	8.0	.9031
1.9	.2788	5.0	.6990	8.1	.9085
2.0	.3010	5.1	.7076	8.2	.9138
2.1	.3222	5.2	.7160	8.3	.9191
2.2	.3424	5.3	.7243	8.4	.9243
2.3	.3617	5.4	.7324	8.5	.9294
2.4	.3802	5.5	.7404	8.6	.9345
2.5	.3979	5.6	.7482	8.7	.9395
2.6	.4150	5.7	.7559	8.8	.9445
2.7	.4314	5.8	.7634	8.9	.9494
2.8	.4472	5.9	.7709	9.0	.9542
2.9	.4624	6.0	.7782	9.1	.9590
3.0	.4771	6.1	.7853	9.2	.9638
3.1	.4914	6.2	.7924	9.3	.9685
3.2	.5051	6.3	.7993	9.4	.9731
3.3	.5185	6.4	.8062	9.5	.9777
3.4	.5315	6.5	.8129	9.6	.9823
3.5	.5441	6 6	.8195	9.7	.9868
3.6	.5563	6.7	.8261	9.8	.9912
3.7	.5682	6.8	.8325	9.9	.9956
3.8	.5798	6.9	.8388	10.0	1.0000
3.9	.5911	7.0	.8451		
4.0	.6021	7.1	.8513		

INSULATION TEMPERATURE LIMITS

Arrangement of materials in descending order of average service temperature limit permits narrowing choice of materials at a glance when temperature dominates specifications for a plastic, ceramic, mica, rubber or foam material in solid, film or other form.

Material	Deg F
Ceramic-Vitreous Enamel on Solid Nickel Wire	1,500
Glass-Ceramic (Pyroceram)	1,300
Solid Alumina	1,300
Ceramic-Vitreous Enamel on Nickel-Clad Copper Wire	1,000
Glass-Bonded Artificial Mica	1,000
Alumina Microspheres	950
Reconstituted Phlogopite Mica	950
Glass Braid on Wire	950
Ceramic Coating on Wire	950
Tin Dioxide-Antimony Oxide Film	950
Magnesia Dielectric Film	950
Boron Nitride Dielectric Film	950
Alumina Dielectric Film	950
Glass-Bonded Natural Mica	900
Forsterite Electron-Tube Spacers	750
Alumina Electron-Tube Spacers	850
Silicone, Foamed-in-Place	700
Polytetrafluoroethylene Film (Teflon)	550±25
Silicone Rubber	550
Silicone, Mineral-Filled	500
Silicone, Glass-Filled	475
Polytetrafluoroethylene (Teflon)	500
Phenol-Formaldehyde, Asbestos-Filled	475±125
Polyester, Asbestos-Filled	450
Fluorinated Acrylic Rubber	450
Methyl Cellulose Film	430
Diallyl Phthalate	400±50
Epoxies, Cast, Unfilled	425±175
Epoxies, Cast, Silica-Filled	425±175
Polytrifluorochloroethylene (Kel-F)	390
Melamines, Glass-Fiber-Filled	350±50
Nylon, Glass-Fiber-Filled	350±50
Cellulose Acetate Foam	350
Alkyds, High-Strength	350
Cellophane	340±35
Polyester, Glass-Filled	325±25
Phenolics, Electrical	325±75
Urethane, Rigid, Foamed-in-Place	325±75
Alkyds, General-Purpose	325±25
Epoxies, Prefoamed	325±20
Cellulose Acetate Film	300±100
Polytrifluorochloroethylene Film	300
Polycarbonate	300
Polypropylene	300±25
Furan	300±30
Polyacrylic Ester	300±50
Polyethylene Terephthalate Film	300
Butyl Rubber	300±50
Allyls, Cast	300
Phenolics, Foamed-in-Place	300
Chlorinated Polyether	290
Nylon 66	290±10
Vinylidene Chloride Film	290±30
Nylon Film	280±100
Casein	275
Melamines, Asbestos-Filled	275±25
Epoxies, Flexible	275±25
Polysulfide-Epoxy, Cast	270±25
Urethane, Flexible, Foamed-in-Place	270±15
Rubber Phenolics	260±40
Polyester, Cast, Rigid or Flexible	250
Melamines, Fabric-Filled	250
Nitrile Rubber	250
Polysulfide Rubber	250
Glyceryl Phthalate	250
Polymethyl Alphachloroacrylate	250
Polyethylene, High-Density	250
Melamines, Cellulose-Filled	250
Phenol-Formaldehyde, Unfilled	250
Neoprene Rubber	240
Urethane Rubber	240
Ethyl Cellulose Film	225
ABS (Acrylonitrile, Butadiene and Styrene) Monomers	225
Acetal (Polyformaldehyde) Resin	225
Chlorinated Acrylic	225
Hard Rubber	220
Polyethylene, Low-Density	210
Allyls, Molded	210
Butadiene-Acronitrile Foam	210
Polyvinyl Chloride Film, Rigid	210±10
Polymethylstyrene	210
Melamines, Unfilled	210
Urea, Prefoamed	200
Epoxies, Foamed-in-Place	200
Polymethyl Methacrylate (Acrylic)	200
Polystyrene Film	200±20
Polyethylene Film	200
Vinyl Nitrile Rubber Blend Film	200
Vinylidene Chloride	190±10
Ethyl Cellulose	190±10
Cellulose Propionate	190±10
Cellulose Acetate Butyrate	190±10
Styrene Sheets, Heat-Resistant	190±10
Polyvinyl Chloride Foam	185±35
Polystyrene, Foamed-in-Place	185
Polyvinyl Chloride, Flexible	180±40
Natural Rubber	180
Styrene-Butadiene Rubber	180
Neoprene Foam	180
Cellulose Acetate	180±40
Styrene Blends	175±25
Polymethyl Methacrylate Film	170±15
Methyl Methacrylate	170±30
Ureas	170
Polyvinyl Chloride Film	170±15
Polystyrene, Unfilled	160±10
Polystyrene, Prefoamed	160
Styrene Sheets, Shock-Resistant	160±15
Natural Rubber Foam	160
Phenolics, Unfilled	160
Styrene-Butadiene Foam	160
Ethyl Cellulose	150±35
Cellulose Acetate Butyrate Film	140
Vinyl Chloride	145±25
Vinyl Formal	140±10
Cellulose Nitrate	140
Vinyl Butyral	110

Where service temperature varies with formulation or purity of a material, average value is given, followed by a value indicating the possible range of variation above and below this value. When a wide range is indicated, always obtain latest specific values from manufacturers of the materials that appear to meet the required temperature specifications

ADHESIVES FOR ELECTRONIC ASSEMBLIES

Chart simplifies choosing best adhesive for a particular electronic assembly. Information is representative of each generic type

Type of Adhesive	Bonding Effectiveness for Ceramic, Glass, Metal, Leather, Rubber, Wood	Cure Temp	Forms Available	Resistance to Cold, Heat, Fungi, Water	Comments and Applications
Epoxy resins	Excellent for all except rubber	Room to 300 F	100% Solids or Solvent	Good for heat to 250 F; excellent for others except possibly water	Many formulations available. Metal filler gives conductive joint. Rubbers may need special treatment
Isocyanate resins (polyurethanes)	Excellent for all	Room to 300 F	100% Solids or Solvent	Excellent for all except some rubbers	Will give bond with only contact pressure at room temperature. Not affected by oils. Bond strength for aluminum to aluminum is over 1,000 psi
Methyl cyanoacrylate monomer	Excellent for all	Room	100% Solids or Solvent	Moderate for water; fair for heat; good for cold	Sets in seconds without pressure, heat or catalysts. Steel-steel bonds give up to 6,500 psi. Good up to 175 F
Phenol-formaldehyde resin	Excellent for wood, rubber, leather; good for ceramic, metal, glass	300 F to 400 F	Solvent only	Excellent for all	Widely used in manufacture of exterior plywood. Bond is more durable than wood itself
Phenolic elastomer resin	Excellent for ceramic, metal, wood; good for others	300 F to 400 F	Solvent only	Excellent for all	Used extensively for bonding metal foils to insulating plastics where resistance to acid and water is essential
Phenolic epoxy resin	Fair for rubber; excellent for others	300 F	100% Solids or Solvent	Excellent for all	Has shown least change in strength of all adhesives at radiation dosage of 10^9 roentgens
Phenolic polyamide resin	Excellent for metal, wood; fair for ceramic, leather; poor for glass, rubber	300 F	Solvent only	Excellent for cold, fungi; moderate for heat; poor for water	Lower in cost than epoxy resin adhesives
Phenolic-vinyl acetals	Excellent for ceramic, glass, metal, wood	200 F	Solvent only	Excellent for fungi, water; moderate for heat, cold	Highly recommended for joining ceramics
Polyamides (nylon)	Excellent for metal, wood; good for ceramic, glass, leather	Fused by heat	100% Solids only	Excellent for fungi, water; moderate for cold, heat	Highly versatile. Used in place of solder for hermetic seals
Polyamide-epoxy resins	Good for rubber; excellent for others	Room to 300 F	100% Solids or Solvent	Good for heat; excellent for others	Commonly used for bonding both thermoplastic and thermosetting plastics. Gives excellent bond to copper
Resorcinol resins (formaldehyde, furfural, urea)	Excellent for rubber, wood, leather; good for ceramic; poor for glass, metal	Room to 200 F	100% Solids or Solvent	Excellent for all	Gives excellent bond also to laminates of phenol and melamine resins. Gives good bond to nylon and many other plastics also
Rubber, neoprene	Excellent for all	Room	Solvent only	Excellent for fungi, water; good for heat, cold	Can serve in place of gasket and reduce bolt requirements on waterproof housings and fittings
Rubber, polysulfide (Thiokol)	Excellent for rubber; good for glass, leather, metal, ceramic, wood	Room	Solvent only	Excellent for fungi; moderate for water; good for cold, heat	Major uses include sealing of connectors around cable wires and other permanent putty applications. Low permeability to gases. Excellent resistance to aging, ozone and sunlight. Resistant to most solvents
Rubber, polysulfide-epoxy	Good for rubber; excellent for others	Room to 200 F	100% Solids or Solvent	Good for heat; excellent for others	
Silicone rubbers	Excellent for ceramic, glass, metal	Room	Solvent only	Excellent for cold, fungi, water; good for heat	Widely used as pressure-sensitive adhesives; retain good strength from —80 F to 500 F
Vinyl acetate resin	Poor for rubber; excellent for others	Fused by heat	Solvent only	Excellent for fungi; moderate for cold, heat; fair for water	Available in polyethylene squeeze bottles ready to use. In general, better results are obtained when at least one of parts being joined is porous enough to absorb moisture released during setting
Vinyl chloride resin	Good for rubber; excellent for others	Fused by heat	Solvent only	Excellent for fungi; moderate for others	

TO CONVERT	INTO	MULTIPLY BY
	A	
acres	sq feet	43,560.0
"	sq meters	4,047.
"	sq miles	1.562×10^{-3}
"	sq yards	4,840.
acre-feet	cu feet	43,560.0
" "	gallons	3.259×10^{5}
amperes/sq cm	amps/sq in.	6.452
" " "	amps/sq meter	10^{4}
amperes/sq in.	amps/sq cm	0.1550
" " "	amps/sq meter	1,550.0
amperes/sq meter	amps/sq cm	10^{-4}
" " "	amps/sq in.	6.452×10^{-4}
ampere-hours	coulombs	3,600.0
" "	faradays	0.03731
ampere-turns	gilberts	1.257
ampere-turns/cm	amp-turns/in.	2.540
" " "	amp-turns/meter	100.0
" " "	gilberts/cm	1.257
ampere-turns/in.	amp-turns/cm	0.3937
" " "	amp-turns/meter	39.37
" " "	gilberts/cm	0.4950
ampere-turns/meter	amp-turns/cm	0.01
" " "	amp-turns/in.	0.0254
" " "	gilberts/cm	0.01257
ares	acres	0.02471
"	sq meters	100.0
atmospheres	cms of mercury	76.0
"	ft of water (at 4°C)	33.90
"	in. of mercury (at 0°C)	29.92
"	kgs/sq cm	1.0333
"	kgs/sq meter	10,332.
"	pounds/sq in.	14.70
"	tons/sq ft	1.058
	B	
barrels (oil)	gallons (oil)	42.0
bars	atmospheres	0.9869
"	dynes/sq cm	10^{6}
"	kgs/sq meter	1.020×10^{4}
"	pounds/sq ft	2,089.
"	pounds/sq in.	14.50
Btu	ergs	1.0550×10^{10}
"	foot-lbs	778.3
"	gram-calories	252.0

TO CONVERT	INTO	MULTIPLY BY
Btu	horsepower-hrs	3.931×10^{-4}
"	joules	1,054.8
"	kilogram-calories	0.2520
"	kilogram-meters	107.5
"	kilowatt-hrs	2.928×10^{-4}
Btu/hr	foot-pounds/sec	0.2162
" "	gram-cal/sec	0.0700
" "	horsepower-hrs	3.929×10^{-4}
" "	watts	0.2931
Btu/min	foot-lbs/sec	12.96
" "	horsepower	0.02356
" "	kilowatts	0.01757
" "	watts	17.57
Btu/sq ft/min	watts/sq in.	0.1221
bushels	cu ft	1.2445
"	cu in.	2,150.4
"	cu meters	0.03524
"	liters	35.24
"	pecks	4.0
"	pints (dry)	64.0
"	quarts (dry)	32.0
	C	
centares (centiares)	sq meters	1.0
Centigrade	Fahrenheit	(C°x9/5) + 32
centigrams	grams	0.01
centiliters	liters	0.01
centimeters	feet	3.281×10^{-2}
"	inches	0.3937
"	kilometers	10^{-5}
"	meters	0.01
"	miles	6.214×10^{-6}
"	millimeters	10.0
"	mils	393.7
"	yards	1.094×10^{-2}
centimeter-dynes	cm-grams	1.020×10^{-3}
" "	meter-kgs	1.020×10^{-8}
" "	pound-feet	7.376×10^{-8}
centimeter-grams	cm-dynes	980.7
" "	meter-kgs	10^{-5}
" "	pound-feet	7.233×10^{-5}
centimeters of mercury	atmospheres	0.01316
" " "	feet of water	0.4461
" " "	kgs/sq meter	136.0
" " "	pounds/sq ft	27.85

TO CONVERT	INTO	MULTIPLY BY
centimeters of mercury	pounds/sq in.	0.1934
centimeters/sec	feet/min	1.1969
" "	feet/sec	0.03281
" "	kilometers/hr	0.036
" "	knots	0.1943
" "	meters/min	0.6
" "	miles/hr	0.02237
" "	miles/min	3.728×10^{-4}
centimeters/sec/sec	feet/sec/sec	0.03281
" " "	kms/hr/sec	0.036
" " "	meters/sec/sec	0.01
" " "	miles/hr/sec	0.02237
circular mils	sq cms	5.067×10^{-6}
" "	sq mils	0.7854
" "	sq inches	7.854×10^{-7}
coulombs	faradays	1.036×10^{-5}
coulombs/sq cm	coulombs/sq in.	64.52
" " "	coulombs/sq meter	10^4
coulombs/sq in.	coulombs/sq cm	0.1550
" " "	coulombs/sq meter	1,550.
coulombs/sq meter	coulombs/sq cm	10^{-4}
" " "	coulombs/sq in.	6.452×10^{-4}
cubic centimeters	cu feet	3.531×10^{-5}
" "	cu inches	0.06102
" "	cu meters	10^{-6}
" "	cu yards	1.308×10^{-6}
" "	gallons (U.S. liq.)	2.642×10^{-4}
" "	liters	0.001
" "	pints (U.S. liq.)	2.113×10^{-3}
" "	quarts (U.S. liq.)	1.057×10^{-3}
cubic feet	bushels (dry)	0.8036
" "	cu cms	28,320.0
" "	cu inches	1,728.0
" "	cu meters	0.02832
" "	cu yards	0.03704
" "	gallons (U.S. liq.)	7.48052
" "	liters	28.32
" "	pints (U.S. liq.)	59.84
" "	quarts (U.S. liq.)	29.92
cubic feet/min	cu cms/sec	472.0
" " "	gallons/sec	0.1247
" " "	liters/sec	0.4720
" " "	pounds of water/min	62.43
cubic feet/sec	million gals/day	0.646317
" " "	gallons/min	448.831
cubic inches	cu cms	16.39
" "	cu feet	5.787×10^{-4}

TO CONVERT	INTO	MULTIPLY BY
cubic inches	cu meters	1.639×10^{-5}
" "	cu yards	2.143×10^{-5}
" "	gallons	4.329×10^{-3}
" "	liters	0.01639
" "	mil-feet	1.061×10^{3}
" "	pints (U.S. liq.)	0.03463
" "	quarts (U.S. liq.)	0.01732
cubic meters	bushels (dry)	28.38
" "	cu cms	10^6
" "	cu feet	35.31
" "	cu inches	61,023.0
" "	cu yards	1.308
" "	gallons (U.S. liq.)	264.2
" "	liters	1,000.0
" "	pints (U.S. liq.)	2,113.0
" "	quarts (U.S. liq.)	1,057.
cubic yards	cu cms	7.646×10^5
" "	cu feet	27.0
" "	cu inches	46,656.0
" "	cu meters	0.7646
" "	gallons (U.S. liq.)	202.0
" "	liters	764.6
" "	pints (U.S. liq.)	1,615.9
" "	quarts (U.S. liq.)	807.9
cubic yards/min	cubic ft/sec	0.45
" " "	gallons/sec	3.367
" " "	liters/sec	12.74

D

days	hours	24.0
"	minutes	1,440.0
"	seconds	86,400.0
decigrams	grams	0.1
deciliters	liters	0.1
decimeters	meters	0.1
degrees (angle)	minutes	60.0
" "	quadrants	0.01111
" "	radians	0.01745
" "	seconds	3,600.0
degrees/sec	radians/sec	0.01745
" "	revolutions/min	0.1667
" "	revolutions/sec	2.778×10^{-3}
dekagrams	grams	10.0
dekaliters	liters	10.0
dekameters	meters	10.0

TO CONVERT	INTO	MULTIPLY BY
ms	grams	1.7718
"	grains	27.3437
"	ounces	0.0625
dynes	grams	1.020×10^{-3}
"	joules/cm	10^{-7}
"	joules/meter (newtons)	10^{-5}
"	kilograms	1.020×10^{-6}
"	poundals	7.233×10^{-5}
"	pounds	2.248×10^{-6}
dynes/sq cm	bars	10^{-6}

E

ergs	Btu	9.480×10^{-11}
"	dyne-centimeters	1.0
"	foot-pounds	7.367×10^{-8}
"	gram-calories	0.2389×10^{-7}
"	gram-cms	1.020×10^{-3}
"	horsepower-hrs	3.7250×10^{-14}
"	joules	10^{-7}
"	kg-calories	2.389×10^{-11}
"	kg-meters	1.020×10^{-8}
"	kilowatt-hrs	0.2778×10^{-13}
"	watt-hours	0.2778×10^{-10}
ergs/sec	Btu/min	$5{,}688 \times 10^{-9}$
" "	ft-lbs/min	4.427×10^{-6}
" "	ft-lbs/sec	7.3756×10^{-8}
" "	horsepower	1.341×10^{-10}
" "	kg-calories/min	1.433×10^{-9}
" "	kilowatts	10^{-10}

F

farads	microfarads	10^{6}
faradays	ampere-hours	26.80
"	coulombs	9.649×10^{4}
fathoms	feet	6.0
feet	centimeters	30.48
"	kilometers	3.048×10^{-4}
"	meters	0.3048
"	miles (naut.)	1.645×10^{-4}
"	miles (stat.)	1.894×10^{-4}
"	millimeters	304.8
"	mils	1.2×10^{4}
feet of water	atmospheres	0.02950

TO CONVERT	INTO	MULTIPLY BY
feet of water	in. of mercury	0.8826
" " "	kgs/sq cm	0.03048
" " "	kgs/sq meter	304.8
" " "	pounds/sq ft	62.43
" " "	pounds/sq in.	0.4335
feet/min	cms/sec	0.5080
" "	feet/sec	0.01667
" "	kms/hr	0.01829
" "	meters/min	0.3048
" "	miles/hr	0.01136
feet/sec	cms/sec	30.48
" "	kms/hr	1.097
" "	knots	0.5921
" "	meters/min	18.29
" "	miles/hr	0.6818
" "	miles/min	0.01136
feet/sec/sec	cms/sec/sec	30.48
" " "	kms/hr/sec	1.097
" " "	meters/sec/sec	0.3048
" " "	miles/hr/sec	0.6818
feet/100 feet	per cent grade	1.0
foot-pounds	Btu	1.286×10^{-3}
" "	ergs	1.356×10^{7}
" "	gram-calories	0.3238
" "	hp-hrs	5.050×10^{-7}
" "	joules	1.356
" "	kg-calories	3.24×10^{-4}
" "	kg-meters	0.1383
" "	kilowatt-hrs	3.766×10^{-7}
foot-pounds/min	Btu/min	1.286×10^{-3}
" " "	foot-pounds/sec	0.01667
" " "	horsepower	3.030×10^{-5}
" " "	kg-calories/min	3.24×10^{-4}
" " "	kilowatts	2.260×10^{-5}
foot-pounds/sec	Btu/hr	4.6263
" " "	Btu/min	0.07717
" " "	horsepower	1.818×10^{-3}
" " "	kg-calories/min	0.01945
" " "	kilowatts	1.356×10^{-3}
furlongs	rods	40.0
"	feet	660.0

G

gallons	cu cms	3,785.0
"	cu feet	0.1337
"	cu inches	231.0

TO CONVERT	INTO	MULTIPLY BY
ons	cu meters	3.785×10^{-3}
"	cu yards	4.951×10^{-3}
"	liters	3.785
"	pints	8.0
"	quarts	4.0
gallons (liq. Br. Imp.)	gallons (U.S. liq.)	1.20095
gallons (U.S.)	gallons (Imp.)	0.83267
gallons of water	pounds of water	8.3453
gallons/min	cu ft/sec	2.228×10^{-3}
" "	liters/sec	0.06308
" "	cu ft/hr	8.0208
gausses	lines/sq in.	6.452
"	webers/sq cm	10^{-8}
"	webers/sq in.	6.452×10^{-8}
"	webers/sq meter	10^{-4}
gilberts	ampere-turns	0.7958
gilberts/cm	amp-turns/cm	0.7958
" "	amp-turns/in	2.021
" "	amp-turns/meter	79.58
gills	liters	0.1183
"	pints (liq.)	0.25
gin	martinis (dry)	20g + 1v
grains (troy)	grains (avdp)	1.0
" "	grams	0.06480
" "	ounces (avdp)	2.0833×10^{-3}
" "	pennyweight (troy)	0.04167
grains/U.S. gal	parts/million	17.118
" " "	pounds/million gal	142.86
grains/Imp. gal	parts/million	14.286
grams	dynes	980.7
"	grains	15.43
"	joules/cm	9.807×10^{-3}
"	joules/meter (newtons)	9.807×10^{-3}
"	kilograms	0.001
"	milligrams	1,000.
"	ounces (avdp)	0.03527
"	ounces (troy)	0.03215
"	poundals	0.07093
"	pounds	2.205×10^{-3}
grams/cm	pounds/inch	5.600×10^{-3}
grams/cu cm	pounds/cu ft	62.43
" " "	pounds/cu in	0.03613
" " "	pounds/mil-foot	3.405×10^{-7}
grams/liter	grains/gal	58.417
" "	pounds/1,000 gal	8.345
" "	pounds/cu ft	0.062427
" "	parts/million	1,000.0

TO CONVERT	INTO	MULTIPLY BY
grams/sq cm	pounds/sq ft	2.0481
gram-calories	Btu	3.9683×10^{-3}
" "	ergs	4.1868×10^{7}
" "	foot-pounds	3.0880
" "	horsepower-hrs	1.5596×10^{-6}
" "	kilowatt-hrs	1.1630×10^{-6}
" "	watt-hrs	1.1630×10^{-3}
gram-calories/sec	Btu/hr	14.286
gram-centimeters	Btu	9.297×10^{-8}
" "	ergs	980.7
" "	joules	9.807×10^{-5}
" "	kg-cal	2.343×10^{-8}
" "	kg-meters	10^{-5}

H

hectares	acres	2.471
"	sq feet	1.076×10^{5}
hectograms	grams	100.0
hectoliters	liters	100.0
hectometers	meters	100.0
hectowatts	watts	100.0
henries	millihenries	1,000.0
horsepower	Btu/min	42.44
"	foot-lbs/min	33,000.
"	foot-lbs/sec	550.0
horsepower (metric) (542.5 ft lb/sec)	horsepower (550 ft lb/sec)	0.9863
horsepower (550 ft lb/sec)	horsepower (metric) (542.5 ft lb/sec)	1.014
horsepower	kg-calories/min	10.68
"	kilowatts	0.7457
"	watts	745.7
horsepower (boiler)	Btu/hr	33.479
" "	kilowatts	9.803
horsepower-hrs	Btu	2,547.
" "	ergs	2.6845×10^{13}
" "	foot-lbs	1.98×10^{6}
" "	gram-calories	641,190.
" "	joules	2.684×10^{6}
" "	kg-calories	641.1
" "	kg-meters	2.737×10^{5}
" "	kilowatt-hrs	0.7457
hours	days	4.167×10^{-2}
"	minutes	60.0
"	seconds	3,600.0

TO CONVERT	INTO	MULTIPLY BY
[illegible]	weeks	5.952×10^{-3}

I

TO CONVERT	INTO	MULTIPLY BY
inches	centimeters	2.540
"	feet	8.333×10^{-2}
"	meters	2.540×10^{-2}
"	miles	1.578×10^{-5}
"	millimeters	25.40
"	mils	1,000.0
"	yards	2.778×10^{-2}
inches of mercury	atmospheres	0.03342
" " "	feet of water	1.133
" " "	kgs/sq cm	0.03453
" " "	kgs/sq meter	345.3
" " "	pounds/sq ft	70.73
" " "	pounds/sq in.	0.4912
inches of water (at 4°C)	atmospheres	2.458×10^{-3}
" " " "	inches of mercury	0.07355
" " " "	kgs/sq cm	2.540×10^{-3}
" " " "	ounces/sq in.	0.5781
" " " "	pounds/sq ft	5.204
" " " "	pounds/sq in.	0.03613

J

TO CONVERT	INTO	MULTIPLY BY
joules	Btu	9.480×10^{-4}
"	ergs	10^7
"	foot-pounds	0.7376
"	kg-calories	2.389×10^{-4}
"	kg-meters	0.1020
"	watt-hrs	2.778×10^{-4}
joules/cm	grams	1.020×10^4
" "	dynes	10^7
" "	joules/meter (newtons)	100.0
" "	poundals	723.3
" "	pounds	22.48

K

TO CONVERT	INTO	MULTIPLY BY
kilograms	dynes	980,665.
"	grams	1,000.0
"	joules/cm	0.09807
"	joules/meter (newtons)	9.807
kilograms	poundals	70.93
"	pounds	2.205
"	tons (long)	9.842×10^{-4}
"	tons (short)	1.102×10^{-3}
kilograms/cu meter	grams/cu cm	0.001
" " "	pounds/cu ft	0.06243
" " "	pounds/cu in.	3.613×10^{-5}
" " "	pounds/mil-foot	3.405×10^{-10}
kilograms/meter	pounds/ft	0.6720
kilograms/sq cm	atmospheres	0.9678
" " "	feet of water	32.81
" " "	inches of mercury	28.96
" " "	pounds/sq ft	2,048.
" " "	pounds/sq in.	14.22
kilograms/sq meter	atmospheres	9.678×10^{-5}
" " "	bars	98.07×10^{-6}
" " "	feet of water	3.281×10^{-3}
" " "	inches of mercury	2.896×10^{-3}
" " "	pounds/sq ft	0.2048
" " "	pounds/sq in.	1.422×10^{-3}
kilograms/sq mm	kgs/sq meter	10^6
kilogram-calories	Btu	3.968
" "	foot-pounds	3,088.
" "	hp-hrs	1.560×10^{-3}
" "	joules	4,186.
" "	kg-meters	426.9
" "	kilojoules	4.186
" "	kilowatt-hrs	1.163×10^{-3}
kilogram meters	Btu	9.294×10^{-3}
" "	ergs	9.804×10^7
" "	foot-pounds	7.233
" "	joules	9.804
" "	kg-calories	2.342×10^{-3}
" "	kilowatt-hrs	2.723×10^{-6}
kilolines	maxwells	1,000.0
kiloliters	liters	1,000.0
kilometers	centimeters	10^5
"	feet	3,281.
"	inches	3.937×10^4
"	meters	1,000.0
"	miles	0.6214
"	millimeters	10^6
"	yards	1,094.
kilometers/hr	cms/sec	27.78
" "	feet/min	54.68
" "	feet/sec	0.9113
" "	knots	0.5396

TO CONVERT	INTO	MULTIPLY BY
kilometers/hr	meters/min	16.67
" "	miles/hr	0.6214
kilometers/hr/sec	cms/sec/sec	27.78
" " "	ft/sec/sec	0.9113
" " "	meters/sec/sec	0.2778
" " "	miles/hr/sec	0.6214
kilowatts	Btu/min	56.92
"	foot-lbs/min	4.426×10^{4}
"	foot-lbs/sec	737.6
"	horsepower	1.341
"	kg-calories/min	14.34
"	watts	1,000.0
kilowatt-hrs	Btu	3,413.
" "	ergs	3.600×10^{13}
" "	foot-lbs	2.655×10^{6}
" "	gram-calories	859,850.
" "	horsepower-hrs	1.341
" "	joules	3.6×10^{6}
" "	kg-calories	860.5
" "	kg-meters	3.671×10^{5}
" "	pounds of water evaporated from and at 212° F.	3.53
" "	pounds of water raised from 62° to 212° F.	22.75
knots	feet/hr	6,080.
"	kilometers/hr	1.8532
"	nautical miles/hr	1.0
"	statute miles/hr	1.151
"	yards/hr	2,027.
"	feet/sec	1.689

L

league	miles (approx.)	3.0
lines/sq cm	gausses	1.0
lines/sq in.	gausses	0.1550
lines/sq in.	webers/sq cm	1.550×10^{-9}
" " "	webers/sq in.	10^{-8}
" " "	webers/sq meter	1.550×10^{-5}
links (engineer's)	inches	12.0
links (surveyor's)	inches	7.92
liters	bushels (U.S. dry)	0.02838
"	cu cm	1,000.0
"	cu feet	0.03531
"	cu inches	61.02
liters	cu meters	0.001
"	cu yards	1.308×10^{-3}
"	gallons (U.S. liq.)	0.2642
"	pints (U.S. liq.)	2.113
"	quarts (U.S. liq.)	1.057
liters/min	cu ft/sec	5.886×10^{-4}
" "	gals/sec	4.403×10^{-3}
lumens/sq ft	foot-candles	1.0
lux	foot-candles	0.0929

M

maxwells	kilolines	0.001
"	webers	10^{-8}
megalines	maxwells	10^{6}
megohms	microhms	10^{12}
"	ohms	10^{6}
meters	centimeters	100.0
"	feet	3.281
"	inches	39.37
"	kilometers	0.001
"	miles (naut.)	5.396×10^{-4}
"	miles (stat.)	6.214×10^{-4}
"	millimeters	1,000.0
"	yards	1.094
"	varas	1.179
meters/min	cms/sec	1.667
" "	feet/min	3.281
" "	feet/sec	0.05468
" "	kms/hr	0.06
" "	knots	0.03238
" "	miles/hr	0.03728
meters/sec	feet/min	196.8
" "	feet/sec	3.281
" "	kilometers/hr	3.6
" "	kilometers/min	0.06
" "	miles/hr	2.237
" "	miles/min	0.03728
meters/sec/sec	cms/sec/sec	100.0
" " "	ft/sec/sec	3.281
" " "	kms/hr/sec	3.6
" " "	miles/hr/sec	2.237
meter-kilograms	cm-dynes	9.807×10^{7}
" "	cm-grams	10^{5}
" "	pound-feet	7.233
microfarad	farads	10^{-6}

TO CONVERT	INTO	MULTIPLY BY
...ograms	grams	10^{-6}
...icrohms	megohms	10^{-12}
"	ohms	10^{-6}
microliters	liters	10^{-6}
miles (naut.)	feet	6,080.27
" "	kilometers	1.853
" "	meters	1,853.
" "	miles (statute)	1.1516
" "	yards	2,027.
miles (statute)	centimeters	1.609×10^{5}
" "	feet	5,280.
" "	inches	6.336×10^{4}
" "	kilometers	1.609
" "	meters	1,609.
" "	miles (naut.)	0.8684
" "	yards	1,760.
miles/hr	cms/sec	44.70
" "	feet/min	88.
" "	feet/sec	1.467
" "	kms/hr	1.609
" "	kms/min	0.02682
" "	knots	0.8684
" "	meters/min	26.82
" "	miles/min	0.01667
miles/hr/sec	cms/sec/sec	44.70
" " "	feet/sec/sec	1.467
" " "	kms/hr/sec	1.609
" " "	meters/sec/sec	0.4470
...iles/min	cms/sec	2,682.
" "	feet/sec	88.
" "	kms/min	1.609
" "	knots/min	0.8684
" "	miles/hr	60.0
mil-feet	cu inches	9.425×10^{-6}
milliers	kilograms	1,000.
milligrams	grams	0.001
milligrams/liter	parts/million	1.0
millihenries	henries	0.001
milliliters	liters	0.001
millimeters	centimeters	0.1
"	feet	3.281×10^{-3}
"	inches	0.03937
"	kilometers	10^{-6}
"	meters	0.001
"	miles	6.214×10^{-7}
"	mils	39.37
"	yards	1.094×10^{-3}

TO CONVERT	INTO	MULTIPLY BY
million gals/day	cu ft/sec	1.54723
mils	centimeters	2.540×10^{-3}
"	feet	8.333×10^{-5}
"	inches	0.001
"	kilometers	2.540×10^{-8}
"	yards	2.778×10^{-5}
miner's inches	cu ft/min	1.5
minutes (angles)	degrees	0.01667
" "	quadrants	1.852×10^{-4}
" "	radians	2.909×10^{-4}
" "	seconds	60.0
myriagrams	kilograms	10.0
myriameters	kilometers	10.0
myriawatts	kilowatts	10.0

N

nepers	decibels	8.686

O

ohms	megohms	10^{-6}
ohms	microhms	10^{6}
ounces	drams	16.0
"	grains	437.5
"	grams	28.349527
"	pounds	0.0625
"	ounces (troy)	0.9115
"	tons (long)	2.790×10^{-5}
"	tons (metric)	2.835×10^{-5}
ounces (fluid)	cu inches	1.805
" "	liters	0.02957
ounces (troy)	grains	480.0
" "	grams	31.103481
" "	ounces (avdp.)	1.09714
" "	pennyweights (troy)	20.0
" "	pounds (troy)	0.08333
ounces/sq in.	pounds/sq in.	0.0625

P

parts/million	grains/U.S. gal	0.0584
" "	grains/Imp. gal	0.07016
" "	pounds/million gal	8.345

TO CONVERT	INTO	MULTIPLY BY
yweights (troy)	grains	24.0
" "	ounces (troy)	0.05
" "	grams	1.55517
" "	pounds (troy)	4.1667×10^{-3}
pints (dry)	cu inches	33.60
pints (liq.)	cu cms.	473.2
" "	cu feet	0.01671
" "	cu inches	28.87
" "	cu meters	4.732×10^{-4}
" "	cu yards	6.189×10^{-4}
" "	gallons	0.125
" "	liters	0.4732
" "	quarts (liq.)	0.5
poundals	dynes	13,826.
"	grams	14.10
"	joules/cm	1.383×10^{-3}
"	joules/meter (newtons)	0.1383
"	kilograms	0.01410
"	pounds	0.03108
pounds	drams	256.
"	dynes	44.4823×10^{4}
"	grains	7,000.
"	grams	453.5924
"	joules/cm	0.04448
"	joules/meter (newtons)	4.448
"	kilograms	0.4536
"	ounces	16.0
"	ounces (troy)	14.5833
"	poundals	32.17
"	pounds (troy)	1.21528
"	tons (short)	0.0005
pounds (troy)	grains	5,760.
" "	grams	373.24177
" "	ounces (avdp.)	13.1657
" "	ounces (troy)	12.0
" "	pennyweights (troy)	240.0
" "	pounds (avdp.)	0.822857
" "	tons (long)	3.6735×10^{-4}
" "	tons (metric)	3.7324×10^{-4}
" "	tons (short)	4.1143×10^{-4}
pounds of water	cu feet	0.01602
" " "	cu inches	27.68
" " "	gallons	0.1198
pounds of water/min	cu ft/sec	2.670×10^{-4}
pound-feet	cm-dynes	1.356×10^{7}
" "	cm-grams	13,825.
" "	meter-kgs	0.1383

TO CONVERT	INTO	MULTIPLY BY
pounds/cu ft	grams/cu cm	0.01602
" " "	kgs/cu meter	16.02
" " "	pounds/cu in.	5.787×10^{-4}
" " "	pounds/mil-foot	5.456×10^{-9}
pounds/cu in.	gms/cu cm	27.68
" " "	kgs/cu meter	2.768×10^{4}
" " "	pounds/cu ft	1,728.
" " "	pounds/mil-foot	9.425×10^{-6}
pounds/ft	kgs/meter	1.488
pounds/in.	gms/cm	178.6
pounds/mil-foot	gms/cu cm	2.306×10^{4}
pounds/sq ft	atmospheres	4.725×10^{-4}
" " "	feet of water	0.01602
" " "	inches of mercury	0.01414
" " "	kgs/sq meter	4.882
" " "	pounds/sq in.	6.944×10^{-3}
pounds/sq in.	atmospheres	0.06804
" " "	feet of water	2.307
" " "	inches of mercury	2.036
" " "	kgs/sq meter	703.1
" " "	pounds/sq ft	144.0

Q

quadrants (angle)	degrees	90.0
" "	minutes	5,400.0
" "	radians	1.571
" "	seconds	3.24×10^{5}
quarts (dry)	cu inches	67.20
quarts (liq.)	cu cms	946.4
" "	cu feet	0.03342
" "	cu inches	57.75
" "	cu meters	9.464×10^{-4}
" "	cu yards	1.238×10^{-3}
" "	gallons	0.25
" "	liters	0.9463

R

radians	degrees	57.30
"	minutes	3,438.
"	quadrants	0.6366
"	seconds	2.063×10^{5}
radians/sec	degrees/sec	57.30
" "	revolutions/min	9.549

TO CONVERT	INTO	MULTIPLY BY
radians/sec	revolutions/sec	0.1592
" /sec/sec	revs/min/min	573.0
" " "	revs/min/sec	9.549
" " "	revs/sec/sec	0.1592
revolutions	degrees	360.0
"	quadrants	4.0
"	radians	6.283
revolutions/min	degrees/sec	6.0
" "	radians/sec	0.1047
" "	revs/sec	0.01667
revolutions/min/min	radians/sec/sec	1.745×10^{-3}
" " "	revs/min/sec	0.01667
" " "	revs/sec/sec	2.778×10^{-4}
revolutions/sec	degrees/sec	360.0
" "	radians/sec	6.283
" "	revs/min	60.0
revolutions/sec/sec	radians/sec/sec	6.283
" " "	revs/min/min	3,600.0
" " "	revs/min/sec	60.0
rods	feet	16.5

S

seconds (angle)	degrees	2.778×10^{-4}
" "	minutes	0.01667
" "	quadrants	3.087×10^{-6}
" "	radians	4.848×10^{-6}
uare centimeters	circular mils	1.973×10^{5}
" "	sq feet	1.076×10^{-3}
" "	sq inches	0.1550
" "	sq meters	0.0001
" "	sq miles	3.861×10^{-11}
" "	sq millimeters	100.0
" "	sq yards	1.196×10^{-4}
square feet	acres	2.296×10^{-5}
" "	circular mils	1.833×10^{8}
" "	sq cms	929.0
" "	sq inches	144.0
" "	sq meters	0.09290
" "	sq miles	3.587×10^{-8}
" "	sq millimeters	9.290×10^{4}
" "	sq yards	0.1111
square inches	circular mils	1.273×10^{6}
" "	sq cms	6.452
" "	sq feet	6.944×10^{-3}
" "	sq millimeters	645.2

TO CONVERT	INTO	MULTIPLY BY
square inches	sq mils	10^{6}
" "	sq yards	7.716×10^{-4}
square kilometers	acres	247.1
" "	sq cms	10^{10}
" "	sq ft	10.76×10^{6}
" "	sq inches	1.550×10^{9}
" "	sq meters	10^{6}
" "	sq miles	0.3861
" "	sq yards	1.196×10^{6}
square meters	acres	2.471×10^{-4}
" "	sq cms	10^{4}
" "	sq feet	10.76
" "	sq inches	1,550.
" "	sq miles	3.861×10^{-7}
" "	sq millimeters	10^{6}
" "	sq yards	1.196
square miles	acres	640.0
" "	sq feet	27.88×10^{6}
" "	sq kms	2.590
" "	sq meters	2.590×10^{6}
" "	sq yards	3.098×10^{6}
square millimeters	circular mils	1,973.
" "	sq cms	0.01
" "	sq feet	1.076×10^{-5}
" "	sq inches	1.550×10^{-3}
square mils	circular mils	1.273
" "	sq cms	6.452×10^{-6}
" "	sq inches	10^{-6}
square yards	acres	2.066×10^{-4}
" "	sq cms	8,361.
" "	sq feet	9.0
" "	sq inches	1,296.
" "	sq meters	0.8361
" "	sq miles	3.228×10^{-7}
" "	sq millimeters	8.361×10^{5}

T

temperature (°C) +273	absolute temperature (°C)	1.0
temperature (°C) +17.78	temperature (°F)	1.8
temperature (°F) +460	absolute temperature (°F)	1.0
temperature (°F) −32	temperature (°C)	5/9
tons (long)	kilograms	1,016.

TO CONVERT	INTO	MULTIPLY BY
tons (long)	pounds	2,240.
" "	tons (short)	1.120
tons (metric)	kilograms	1,000.
" "	pounds	2,205.
tons (short)	kilograms	907.1848
" "	ounces	32,000.
" "	ounces (troy)	29,166.66
" "	pounds	2,000.
" "	pounds (troy)	2,430.56
" "	tons (long)	0.89287
" "	tons (metric)	0.9078
tons (short)/sq ft	kgs/sq meter	9,765.
" " " "	pounds/sq in.	2,000.
tons of water/24 hrs	pounds of water/hr	83.333
" " " " "	gallons/min	0.16643
" " " " "	cu ft/hr	1.3349

W

watts	Btu/hr	3.4192
"	Btu/min	0.05688
"	ergs/sec	107.
"	foot-lbs/min	44.27
"	foot-lbs/sec	0.7378
"	horsepower	1.341×10^{-3}
"	horsepower (metric)	1.360×10^{-3}
"	kg-calories/min	0.01433
"	kilowatts	0.001
watt-hours	Btu	3.413
" "	ergs	3.60×10^{10}
" "	foot-pounds	2,656.
" "	gram-calories	859.85
" "	horsepower-hrs	1.341×10^{-3}
" "	kilogram-calories	0.8605
" "	kilogram-meters	367.2
" "	kilowatt-hrs	0.001
webers	maxwells	10^8
"	kilolines	10^5
webers/sq in.	gausses	1.550×10^7
" " "	lines/sq in.	10^8
" " "	webers/sq cm	0.1550
" " "	webers/sq meter	1,550.
webers/sq meter	gausses	10^4
" " "	lines/sq in.	6.452×10^4
" " "	webers/sq cm	10^{-4}
" " "	webers/sq in.	6.452×10^{-4}

TO CONVERT	INTO	MULTIPLY BY

Y

yards	centimeters	91.44
"	feet	3.0
"	inches	36.0
"	kilometers	9.144×10^{-4}
"	meters	0.9144
"	miles (naut.)	4.934×10^{-4}
"	miles (stat.)	5.682×10^{-4}
"	millimeters	914.4

NEW METRIC UNIT PREFIXES

The National Bureau of Standards scientists have decided to follow the recommendations of the International Committee on Weights and Measures to use new prefixes for denoting multiples and submultiples of metric units.

The International Committee adopted the prefixes at its meeting in Paris in the fall of 1958.

Prefixes to be used by the Bureau of Standards are listed in the October, 1959, issue of NBS's Technical News Bulletin.

In addition to the numerical prefixes already in common use, the Committee expanded the list by adding the four prefixes marked with an asterisk. Thus, for example, 10^{-12} farad is to be called 1 picofarad . . . replacing the designation "1 micromicrofarad" which some engineers have been using.

Multiples	Prefixes	Multiples	Prefixes
10^{12}	tera-*	10^{-1}	deci-
10^{9}	giga-*	10^{-2}	centi-
10^{6}	mega-	10^{-3}	milli-
10^{4}	myria-	10^{-6}	micro-
10^{3}	kilo-	10^{-9}	nano-*
10^{2}	hekto-	10^{-12}	pico-*
10	deka-		

*(tēr'a, jī'ga, nā'no, pī'co).

METRIC CONVERSION TABLE

The convenient table on the following page provides a fast and easy means of conversion from one metric notation to another, including the newly designated units mentioned above. The value labelled "Unit" represents the basic units of measurement, such as ohms, watts, amperes, grams, etc. First, locate the original or given value in the left-hand column. Follow this line horizontally to the vertical column headed by the prefix of the desired value. The figure and arrow at this intersection represent the direction in which the decimal point should be moved and the number of places to move it.

EXAMPLE: Convert 0.15 kilowatts to watts. Starting at the "Kilo-" box in the left-hand column, move horizontally to the column headed by "Unit" (since **watt** is a basic unit of measurement), and read 3—➤. Thus 0.15 kilowatts is the equivalent of 150 watts.

EXAMPLE: Convert 4,500 kilocycles to megacycles, read in the box horizontal to "Kilo-" and under "Mega-" the notation ➤—3, which means a shift of the decimal point three places to the left. Thus 4,500 kilocycles is the equivalent of 4.5 megacycles.

METRIC CONVERSION TABLE

ORIGINAL VALUE	DESIRED VALUE													
	Tera-	Giga-	Mega-	Myria-	Kilo-	Hekto-	Deka-	Units	Deci-	Centi-	Milli-	Micro-	Nano-	Pico-
Tera-		3→	6→	8→	9→	10→	11→	12→	13→	14→	15→	18→	21→	24→
Giga-	←3		3→	5→	6→	7→	8→	9→	10→	11→	12→	15→	18→	21→
Mega-	←6	←3		2→	3→	4→	5→	6→	7→	8→	9→	12→	15→	18→
Myria-	←8	←5	←2		1→	2→	3→	4→	5→	6→	7→	10→	13→	16→
Kilo-	←9	←6	←3	←1		1→	2→	3→	4→	5→	6→	9→	12→	15→
Hekto-	←10	←7	←4	←2	←1		1→	2→	3→	4→	5→	8→	11→	14→
Deka-	←11	←8	←5	←3	←2	←1		1→	2→	3→	4→	7→	10→	13→
Units	←12	←9	←6	←4	←3	←2	←1		1→	2→	3→	6→	9→	12→
Deci-	←13	←10	←7	←5	←4	←3	←2	←1		1→	2→	5→	8→	11→
Centi-	←14	←11	←8	←6	←5	←4	←3	←2	←1		1→	4→	7→	10→
Milli-	←15	←12	←9	←7	←6	←5	←4	←3	←2	←1		3→	6→	9→
Micro-	←18	←15	←12	←10	←9	←8	←7	←6	←5	←4	←3		3→	6→
Nano-	←21	←18	←15	←13	←12	←11	←10	←9	←8	←7	←6	←3		3→
Pico-	←24	←21	←18	←16	←15	←14	←13	←12	←11	←10	←9	←6	←3	

	Practical Unit	Cgs Electromagnetic Unit	Cgs Electrostatic Unit
Emf	volt = 10^{8} abvolts volt = 3.3×10^{-3} statvolt	abvolt = 10^{-8} volt abvolt = 3.3×10^{-11} statvolt	statvolt = 300 volts (approx.) statvolt = 3×10^{10} abvolts
Resistance	ohm = 10^{9} abohms ohm = 1.1×10^{-12} statohm	abohm = 10^{-9} ohm abohm = 1.1×10^{-21} statohm	statohm = 9×10^{11} ohms statohm = 9×10^{20} abohms
Current	ampere = 10^{-1} abampere ampere = 3×10^{9} statamperes	abampere = 10 amperes abampere = 3×10^{10} statamperes	statampere = 3.3×10^{-10} ampere statampere = 3.3×10^{-11} abampere
Quantity	coulomb = 10^{-1} abcoulomb coulomb = 3×10^{9} statcoulombs	abcoulomb = 10 coulombs abcoulomb = 3×10^{10} statcoulombs	statcoulomb = 3.3×10^{-10} coulomb statcoulomb = 3.3×10^{-11} abcoulomb
Capacitance	farad = 10^{-9} abfarad farad = 9×10^{11} statfarads	abfarad = 10^{9} farads abfarad = 9×10^{20} statfarads	statfarad = 1.1×10^{-12} farad statfarad = 1.1×10^{-21} abfarad
Inductance	henry = 10^{9} abhenries henry = 1.1×10^{-12} stathenry	abhenry = 10^{-9} henry abhenry = 1.1×10^{21} stathenries	stathenry = 9×10^{11} henries stathenry = 9×10^{20} abhenries
Energy	joule = 10^{7} ergs	erg = 10^{-7} joule	erg = 10^{-7} joule
Power	watt = 10^{7} $\frac{\text{ergs}}{\text{sec}}$	erg = 10^{-7} watt $\frac{\text{erg}}{\text{sec}}$	$\frac{\text{erg}}{\text{sec}}$ = 10^{-7} watt

AE
CAN
DO

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STATHAM LABORATORIES

Instrument Notes

No. 12 *November-December, 1949*

THE MEANING OF "NATURAL FREQUENCY"

In Instrument Notes No. 2 a summary of the well-known analysis of a simple vibratory system was presented, and it was shown that certain simple parameters were sufficient to specify this system. For example, a natural frequency, a damping ratio, and a sensitivity factor are sufficient to determine the whole response of many common measuring instruments. Because these three factors also offer simple figures of merit for certain comparisons, they are prominent in specifications and data evaluation procedures. In spite of the existence of a rigorous definition of natural frequency in this class of vibrating systems, there are three confusing terms in use: natural frequency, undamped natural frequency, and damped natural frequency. It is evident as one reads the literature that a difference in usage exists and, indeed, that the three terms mentioned above are often applied to a variety of parameters.

In a system containing a mass and a spring restraint, the natural frequency is given by

$$2\pi f_n = \sqrt{K/M}$$

Whether or not there is viscous damping in the system has nothing to do with the natural frequency f_n, and the damping can be varied at will without altering f_n.

If we apply sinusoidal inputs to this instrument and measure the response, we will often find a frequency at which the response is at a maximum. The frequency at this maximum is *not* the natural frequency. Only if the damping is zero does the maximum response occur at the natural frequency. As the damping is increased, the frequency at which peak response occurs is lowered and, at a damping ratio of $1/\sqrt{2}$, the peak response is at zero frequency. For greater damping, no real maximum exists at all. The frequency at which maximum response occurs is shown in Fig. 1.

If this instrument is displaced and then allowed to execute a typical damped transient, it may be found that the transient decay is oscillatory and a frequency may be assigned to it. This is *not* the natural frequency. Only at zero damping is the frequency of the oscillatory transient the same as the natural frequency. As the damping is increased, the frequency of oscillation decreases and, at a damping ratio of unity (by definition), the oscillatory nature of the transient has entirely disappeared. The frequency of transient oscillation is plotted in Fig. 2.

In the argument above, it was assumed that the damping could be varied without affecting either the spring constant or the suspended mass of the instrument. Such is the case with magnetic damping, where a magnetic field can be varied without altering the suspended mass. Such is not the case with fluid damping, and therein lies a trap for the unwary. If the fluid is removed from a fluid-damped instrument, it is an elementary procedure to determine the frequency of free oscillation of the system, and the natural frequency of the instrument *without fluid* is thus determined. If the fluid is replaced, one unfortunately has a different system with a new value of mass, and the previously determined natural frequency does not apply to it, and has no meaning when used to describe it. Since a damping fluid has mass and, in order to damp, must be moved by the suspended mass, it consequently has kinetic energy and, hence, a reaction on the suspended mass. The system thus has an entirely new and larger value of mass—an equivalent mass, if that term describes it better. This effect can easily be found by filling an instrument with a fluid of low viscosity. The damping may still be so small that free transient oscillations of slow decay can be initiated, but they will be found to be markedly lower in frequency than those in air—lower, perhaps, by a factor of two or even ten. To term the natural frequency with liquid filling the damped natural frequency is hardly relevant. The addition of fluid has created an entirely new system with new parameters and a new natural frequency and the damping still has nothing to do with it. This can be demonstrated if a series of liquids with the same density but varying viscosities is employed.

The terms damped natural frequency and undamped natural frequency, whatever they may be intended to mean, appear to have no usefulness in the specification of the characteristics of a basic instrument. The term natural frequency, however, is adequate and unambiguous. Needless to say, the natural frequency may be difficult to determine in a properly damped instrument, and a critical attitude should be maintained toward measurements made by undisclosed techniques.

—G. E. WHITE

THE ENERGY LEVEL OF THINGS

Reprinted from the October 3, 1960 issue of MISSILES AND ROCKETS, 1001 Vermont Avenue, N.W., Washington 5. D.C. U.S.A.

J. R. Williams
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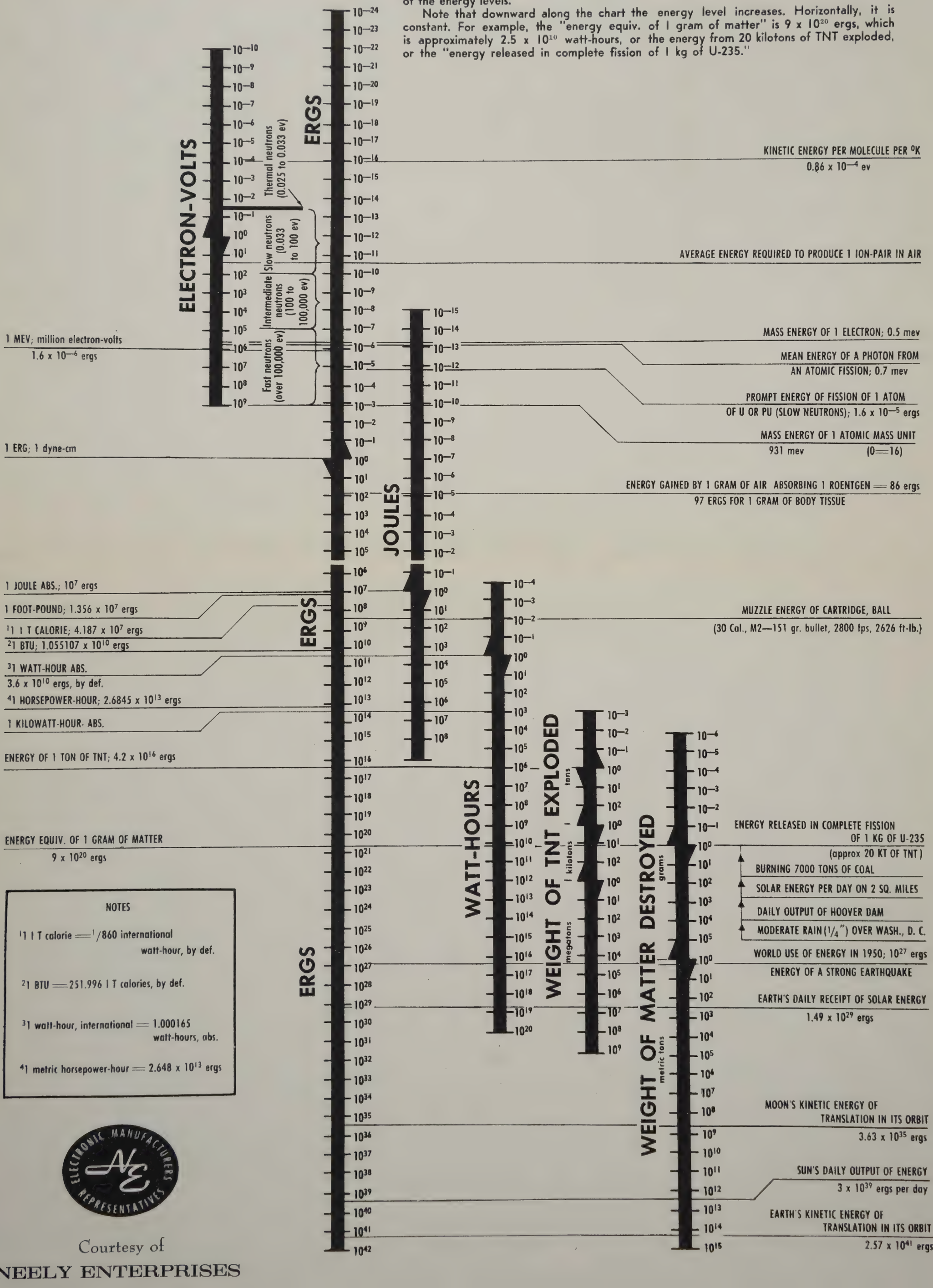
Kirtland Air Force Base, New Mexico

OFTEN THE ENERGY UNITS used in one scientific field are not easily put into perspective by workers in another field. Thus, while certain units are utterly familiar to particular specialists, other units seem to exist only to confound. This chart has been designed to relate several commonly used units and to give "real life" benchmarks to a few of the energy levels.

Note that downward along the chart the energy level increases. Horizontally, it is constant. For example, the "energy equiv. of 1 gram of matter" is 9×10^{20} ergs, which is approximately 2.5×10^{10} watt-hours, or the energy from 20 kilotons of TNT exploded, or the "energy released in complete fission of 1 kg of U-235."


ELECTRON-VOLTS
ERGS
JOULES
ERGS
WATT-HOURS
WEIGHT OF TNT EXPLODED
kilotons
megatons
WEIGHT OF MATTER DESTROYED
grams
metric tons
Thermal neutrons (0.025 to 0.033 ev)
Slow neutrons (0.033 to 100 ev)
Intermediate neutrons (100 to 100,000 ev)
Fast neutrons (over 100,000 ev)
KINETIC ENERGY PER MOLECULE PER °K
0.86 x 10⁻⁴ ev
AVERAGE ENERGY REQUIRED TO PRODUCE 1 ION-PAIR IN AIR
1 MEV; million electron-volts
1.6 x 10⁻⁶ ergs
MASS ENERGY OF 1 ELECTRON; 0.5 mev
MEAN ENERGY OF A PHOTON FROM AN ATOMIC FISSION; 0.7 mev
PROMPT ENERGY OF FISSION OF 1 ATOM OF U OR PU (SLOW NEUTRONS); 1.6 x 10⁻⁵ ergs
MASS ENERGY OF 1 ATOMIC MASS UNIT
931 mev (0=16)
1 ERG; 1 dyne-cm
ENERGY GAINED BY 1 GRAM OF AIR ABSORBING 1 ROENTGEN = 86 ergs
97 ERGS FOR 1 GRAM OF BODY TISSUE
1 JOULE ABS.; 10⁷ ergs
1 FOOT-POUND; 1.356 x 10⁷ ergs
[1]1 I T CALORIE; 4.187 x 10⁷ ergs
[2]1 BTU; 1.055107 x 10¹⁰ ergs
MUZZLE ENERGY OF CARTRIDGE, BALL
(30 Cal., M2—151 gr. bullet, 2800 fps, 2626 ft-lb.)
[3]1 WATT-HOUR ABS.
3.6 x 10¹⁰ ergs, by def.
[4]1 HORSEPOWER-HOUR; 2.6845 x 10¹³ ergs
1 KILOWATT-HOUR· ABS.
ENERGY OF 1 TON OF TNT; 4.2 x 10¹⁶ ergs
ENERGY RELEASED IN COMPLETE FISSION OF 1 KG OF U-235
(approx 20 KT OF TNT)
BURNING 7000 TONS OF COAL
SOLAR ENERGY PER DAY ON 2 SQ. MILES
DAILY OUTPUT OF HOOVER DAM
MODERATE RAIN (1/4") OVER WASH., D. C.
ENERGY EQUIV. OF 1 GRAM OF MATTER
9 x 10²⁰ ergs
WORLD USE OF ENERGY IN 1950; 10²⁷ ergs
ENERGY OF A STRONG EARTHQUAKE
EARTH'S DAILY RECEIPT OF SOLAR ENERGY
1.49 x 10²⁹ ergs
MOON'S KINETIC ENERGY OF TRANSLATION IN ITS ORBIT
3.63 x 10³⁵ ergs
SUN'S DAILY OUTPUT OF ENERGY
3 x 10³⁹ ergs per day
EARTH'S KINETIC ENERGY OF TRANSLATION IN ITS ORBIT
2.57 x 10⁴¹ ergs

NOTES

[1]1 I T calorie = 1/860 international watt-hour, by def.

[2]1 BTU = 251.996 I T calories, by def.

[3]1 watt-hour, international = 1.000165 watt-hours, abs.

[4]1 metric horsepower-hour = 2.648×10^{13} ergs

ELECTRONIC MANUFACTURERS REPRESENTATIVES

Courtesy of
NEELY ENTERPRISES

STATHAM LABORATORIES

Instrument Notes

No. 12 *November-December, 1949*

THE MEANING OF "NATURAL FREQUENCY"

In Instrument Notes No. 2 a summary of the well-known analysis of a simple vibratory system was presented, and it was shown that certain simple parameters were sufficient to specify this system. For example, a natural frequency, a damping ratio, and a sensitivity factor are sufficient to determine the whole response of many common measuring instruments. Because these three factors also offer simple figures of merit for certain comparisons, they are prominent in specifications and data evaluation procedures. In spite of the existence of a rigorous definition of natural frequency in this class of vibrating systems, there are three confusing terms in use: natural frequency, undamped natural frequency, and damped natural frequency. It is evident as one reads the literature that a difference in usage exists and, indeed, that the three terms mentioned above are often applied to a variety of parameters.

In a system containing a mass and a spring restraint, the natural frequency is given by

$$2\pi f_n = \sqrt{K/M}$$

Whether or not there is viscous damping in the system has nothing to do with the natural frequency f_n, and the damping can be varied at will without altering f_n.

If we apply sinusoidal inputs to this instrument and measure the response, we will often find a frequency at which the response is at a maximum. The frequency at this maximum is *not* the natural frequency. Only if the damping is zero does the maximum response occur at the natural frequency. As the damping is increased, the frequency at which peak response occurs is lowered and, at a damping ratio of $1/\sqrt{2}$, the peak response is at zero frequency. For greater damping, no real maximum exists at all. The frequency at which maximum response occurs is shown in Fig. 1.

If this instrument is displaced and then allowed to execute a typical damped transient, it may be found that the transient decay is oscillatory and a frequency may be assigned to it. This is *not* the natural frequency. Only at zero damping is the frequency of the oscillatory transient the same as the natural frequency. As the damping is increased, the frequency of oscillation decreases and, at a damping ratio of unity (by definition), the oscillatory nature of the transient has entirely disappeared. The frequency of transient oscillation is plotted in Fig. 2.

In the argument above, it was assumed that the damping could be varied without affecting either the spring constant or the suspended mass of the instrument. Such is the case with magnetic damping, where a magnetic field can be varied without altering the suspended mass. Such is not the case with fluid damping, and therein lies a trap for the unwary. If the fluid is removed from a fluid-damped instrument, it is an elementary procedure to determine the frequency of free oscillation of the system, and the natural frequency of the instrument *without fluid* is thus determined. If the fluid is replaced, one unfortunately has a different system with a new value of mass, and the previously determined natural frequency does not apply to it, and has no meaning when used to describe it. Since a damping fluid has mass and, in order to damp, must be moved by the suspended mass, it consequently has kinetic energy and, hence, a reaction on the suspended mass. The system thus has an entirely new and larger value of mass—an equivalent mass, if that term describes it better. This effect can easily be found by filling an instrument with a fluid of low viscosity. The damping may still be so small that free transient oscillations of slow decay can be initiated, but they will be found to be markedly lower in frequency than those in air—lower, perhaps, by a factor of two or even ten. To term the natural frequency with liquid filling the damped natural frequency is hardly relevant. The addition of fluid has created an entirely new system with new parameters and a new natural frequency and the damping still has nothing to do with it. This can be demonstrated if a series of liquids with the same density but varying viscosities is employed.

The terms damped natural frequency and undamped natural frequency, whatever they may be intended to mean, appear to have no usefulness in the specification of the characteristics of a basic instrument. The term natural frequency, however, is adequate and unambiguous. Needless to say, the natural frequency may be difficult to determine in a properly damped instrument, and a critical attitude should be maintained toward measurements made by undisclosed techniques.

—G. E. WHITE

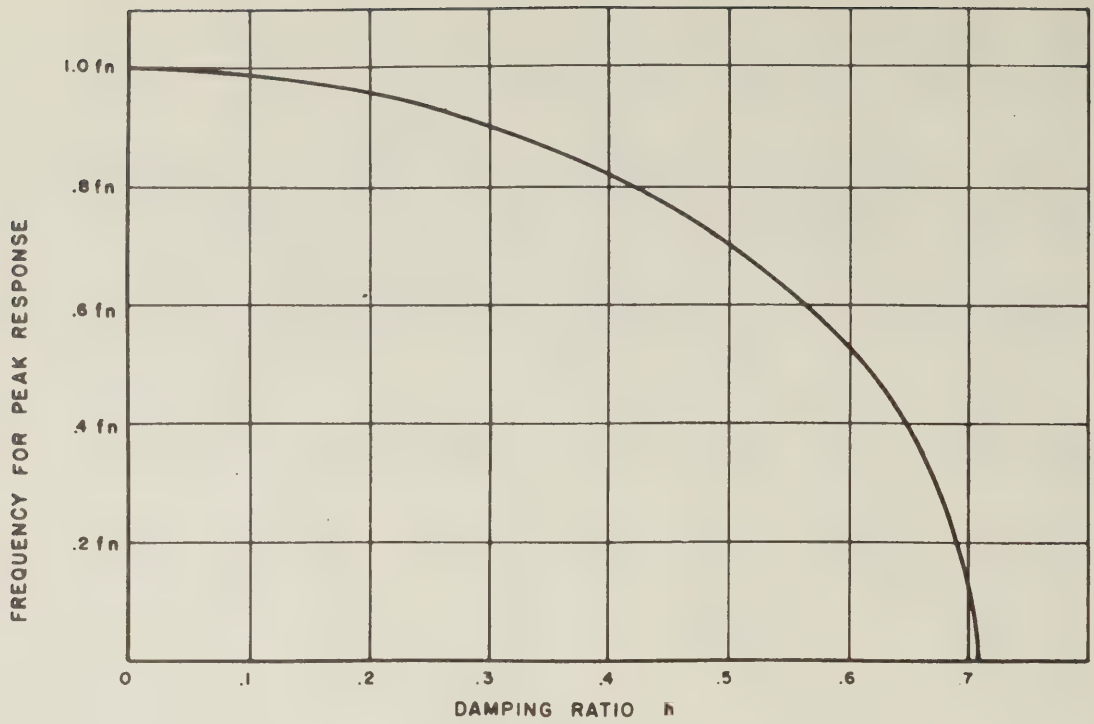


FIG. 1 FREQUENCY FOR PEAK SINUSOIDAL RESPONSE VERSUS DAMPING RATIO

$$f_n\sqrt{1-2h^2}$$

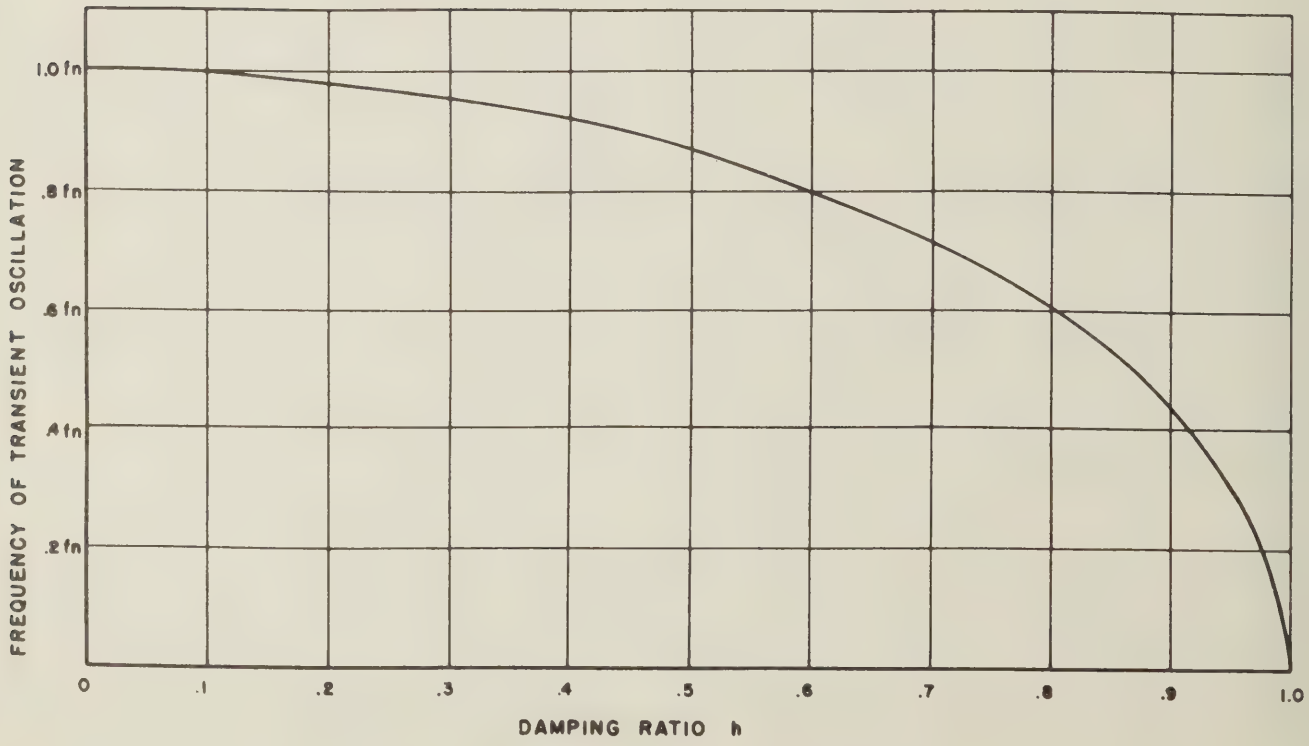


FIG. 2 FREQUENCY OF TRANSIENT OSCILLATION VERSUS DAMPING RATIO,

$$f_n\sqrt{1-h^2}$$

The first issue of Instrument Notes announced that our house organ would be devoted to the dissemination of technical information in the physical measurement field of applied physics. From the first mailing to five hundred correspondents made two years ago, the mailing list has grown to include approximately three thousand assorted engineers, physicists, educators, clinicians, and technologists here in the United States and in Canada, Europe, South America, Africa, and Australia. The reception afforded our offering has been extremely gratifying, and we wish to express our appreciation for the comments, suggestions, and criticisms which we have received from an ever widening circle of readers.

From time to time we have received requests for back issues of Instrument Notes and we have been happy to fill such requests. We have a limited supply of all copies of the Notes so, if your file is incomplete, please write for those numbers which you need. An index of Instrument Notes is given for convenient reference.

INDEX

"Response of Accelerometers to Rotation"
No. 1, Feb. 1948

"Response Characteristics of a Simple Instrument"
No. 2, Apr-May 1948

"Change in Resistance of a Stretched Wire"
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**"Note on Indicating and Recording Instruments"
No. 4, Aug-Sep 1948

"Temperature Compensation of Bridge Type Transducers"
No. 5, Oct-Nov 1948

"Calibration and Test of Accelerometers"
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*"Note on Electrical Resistivity"
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"Design Parameters for Linear Accelerometers"
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*"Frequency Calibration of Systems for Direct Registration of Vascular Pressures"
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"The Meaning of 'Natural Frequency' "
No. 12, Nov-Dec 1949

*Contributed articles
**Revised November 1949

STATHAM

SUBMINIATURE ACCELEROMETER
MODEL F

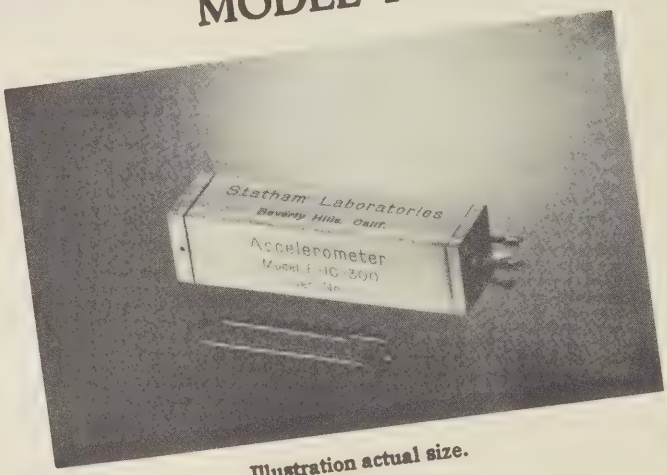


Illustration actual size.
Weight — 23 grams.
Direction of sensitivity normal to long axis.

We are proud to present the Statham Model F accelerometer for the measurement of acceleration in applications requiring miniature components. Weighing less than one ounce, the Model F can be attached to light machine parts without altering their dynamic performance, or it may be inserted into spaces previously inaccessible for vibration measurements.

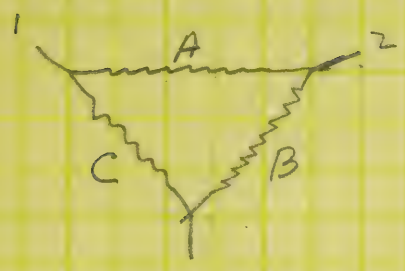
The sensing element of the Model F subminiature accelerometer is the "unbonded strain gage" which assures the user that extremely small size and weight have been emphasized at no sacrifice in performance. As with all Statham instruments, auxiliary equipment requirements are simple. A new catalog sheet, Bulletin No. 4.0, listing ranges, resistances, natural frequencies, and outputs for Model F accelerometers is available upon request.

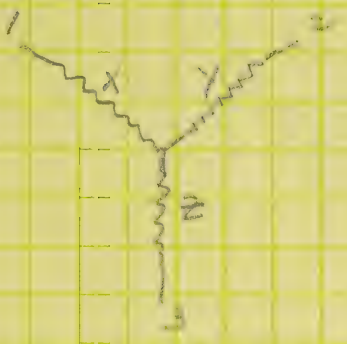
The principles of operation employed in Statham accelerometers are discussed in Instrument Notes No. 9, while suggested recording circuits are outlined in Instrument Notes No. 4. These issues of our house organ may be had upon request.

STATHAM LABORATORIES SCIENTIFIC INSTRUMENTS

12401 WEST OLYMPIC BLVD. • LOS ANGELES 64, CALIFORNIA

FROM Δ TO Y





A, B & C ARE KNOWN.

Δ Y

1 R_T FROM 1 TO 2 = $\frac{A(B+C)}{A+B+C} = X+Y$

2 R_T FROM 2-3 = $\frac{B(A+C)}{A+B+C} = Y+Z$

3 R_T FROM 1-3 = $\frac{C(A+B)}{A+B+C} = X+Z$

SOLVING THREE SIMULTANEOUS EQUATIONS FOR THREE UNKNOWNS:

1 $\frac{AB+AC}{A+B+C} = X+Y$

2 $\frac{AB+BC}{A+B+C} = Y+Z$

} SUBTRACT #2 FROM #1 = $\frac{AC-BC}{A+B+C} = X-Z$

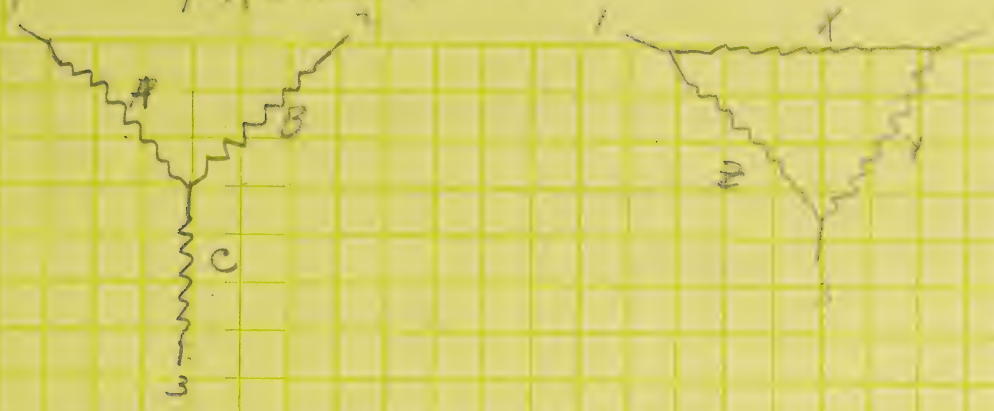
3 $\frac{AC+BC}{A+B+C} = X+Z$

} ADD #3 TO RESULT = $\frac{AC}{A+B+C} = X$

GENERAL FORMULA:

$X = \frac{AC}{A+B+C}$ $Y = \frac{AB}{A+BC}$ $Z = \frac{BC}{A+B+C}$

FROM Y TO Δ

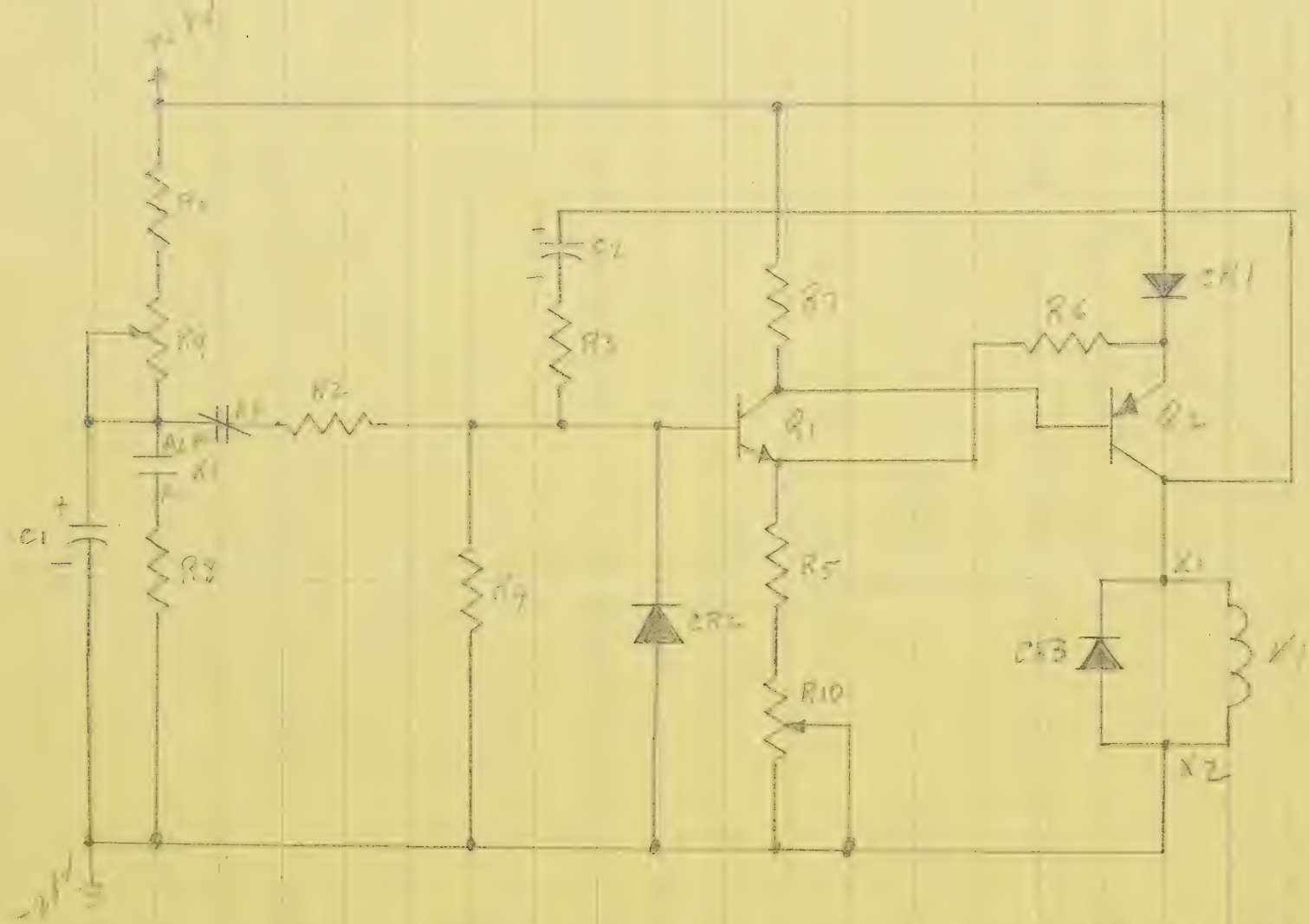


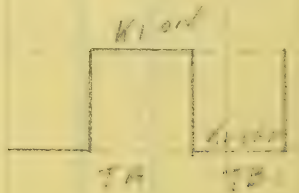
USING THE SAME PROCEDURE AS BEFORE AND SOLVING THE THREE EQUATIONS FOR A, B, C. THE GENERAL FORMULA IS:

$$A = \frac{BA + CA + CB}{C}$$

$$Y = \frac{BA + CA + CB}{A}$$

$$Z = \frac{BA + CA + CB}{B}$$





TA = 200 MS BY R10
TB = 200 MS BY R9

R1 = 4.7 K 5% ½ W.
R2 = 10 K " "
R3 = 4.7 K " "
R4 = 15 K " "
R5 = 3.3 K " "

R6 = 2.0 K 5% 1 W.
R7 = 2.7 K " "
R8 = 1000 Ω " "
R9 = 1K POT
R10 = 1M POT

K1 = C.P. CLARE
RP7632-G1

C1 = 50 MF/ -15% +10% 400 V.D.C.
C2 = 25 MF/ -15% +10% 300 V.D.C.
CR1 = IN458A
CR2 = IN458A
CR3 = IN458A
Q1 = 2N167
Q2 = 2N526

REVISED:

	Prepared	Approved	Approved	Approved
NAME				
DATE				

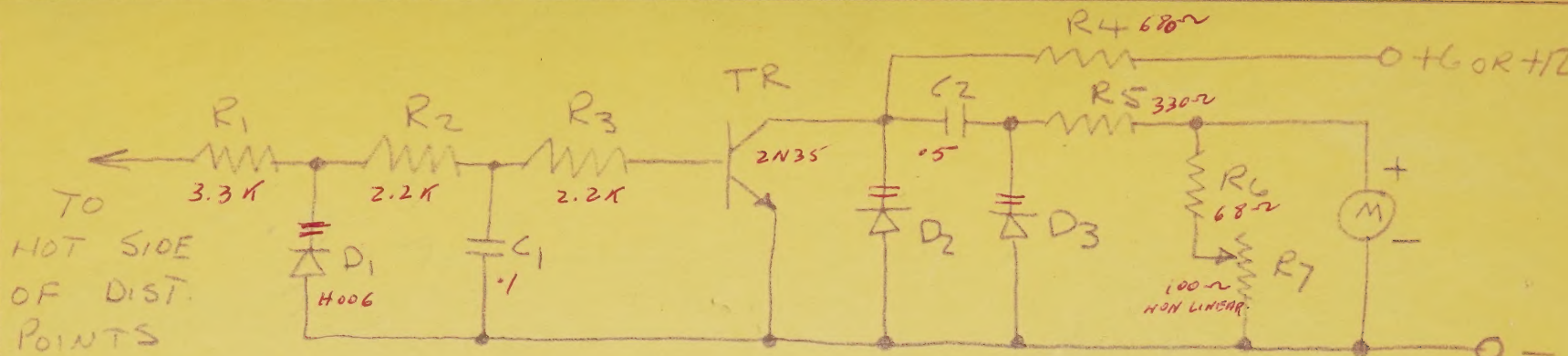
TYPE: SPECIFICATION

TITLE:

LOCKHEED AIRCRAFT CORPORATION
MISSILE SYSTEMS DIVISION
VAN NUYS, CALIF.

SHEET OF

FORM MSD 675



CAL. METER WITH "SUN" TACH.,
INCREASE VALUE OF R_6 WILL
GIVE HIGHER READING

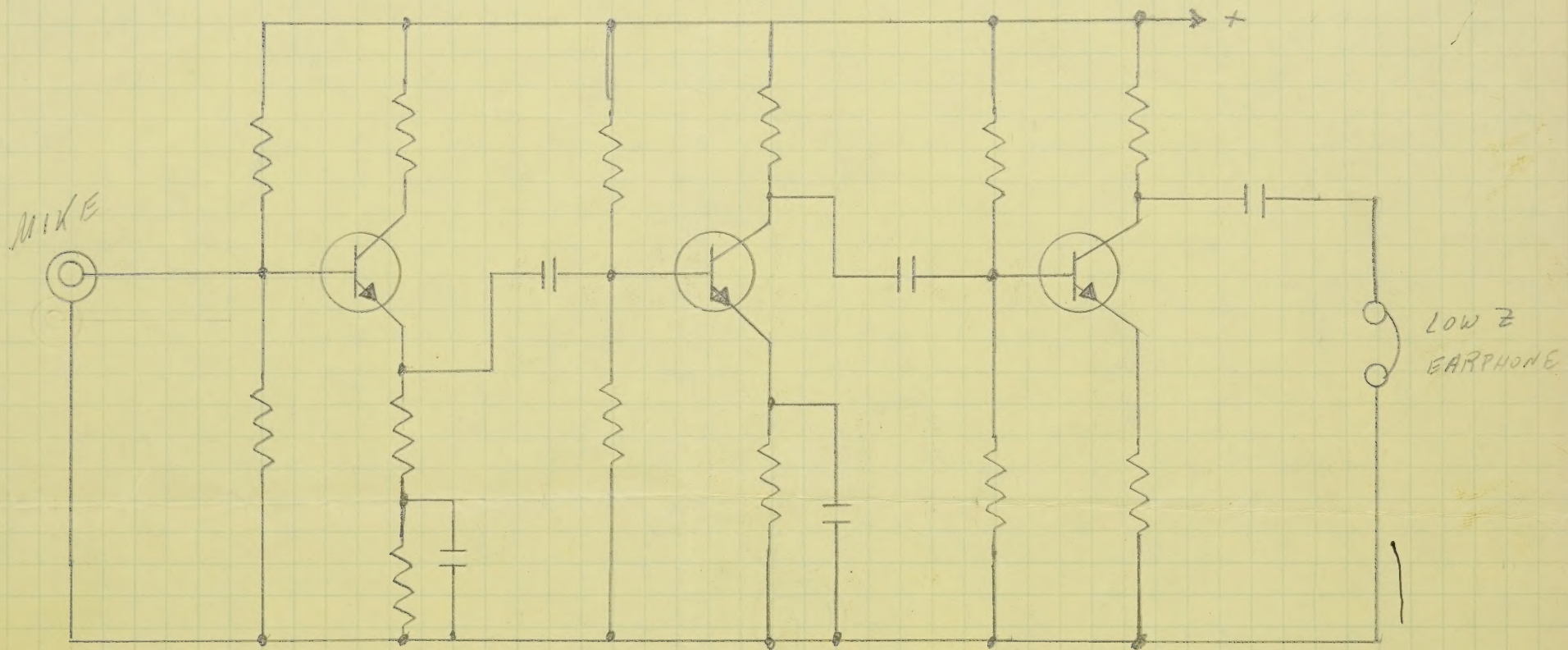
METER FACE MAY BE MODIFIED,
NUMBERS 1-5 = RPM X 1000

$$f = \frac{\#C \times RPM}{120}$$

PARTS LIST

R1	3.3K	½ W
R2 & R3	2.2K	"
R4	680Ω	"
R5	330Ω	"
R6	68Ω	"
R7	100Ω	NON LIN. POT
C1	.1 μf	15 VDC
C2	.5 μf	15 VDC
D1 & D3	H006 OR IN90	
D2	12V - 5V11 OR IN757	
	6V - IN751	
TR	2N35	
M	12 V, 0-1 MA D.C.	
	6 V, 0-500 μA D.C.	

2 4
OL. 2415-0


MIKE
+
LOW Z
EARPHONE

GUS LUCAS
5137 GRANADA STREET
LOS ANGELES 42, CALIF.